

W. Andrew Eglseder

# Atlas of Upper Extremity Trauma

A Clinical Perspective

*Content Editor*  
Kate Eglseder



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W. Andrew Eglseder, Jr., MD  
Professor of Orthopaedics  
University of Maryland School of Medicine  
Attending Orthopaedic and Hand Surgeon  
R. Adams Cowley Shock Trauma Center  
University of Maryland Medical Center  
Baltimore, MD  
USA

Kate Eglseder, ScD, OTR/L, CLT  
Coordinating Editor

Margaret Osburn  
Line/Copyeditor

Coos Hamburger  
Photographer

Mark J Wieber, MA, RN, CNOR  
[Medical] Illustrator

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## Foreword

A trauma center's approach to upper extremity injury is frequently divided among several services, the clinical models being based either on anatomy (shoulder to elbow, forearm and hand, general upper extremity to the wrist and hand) or on systems (musculoskeletal, vascular, and microsurgical). It is rare that injuries to the upper extremity (essentially the entire forearm) would be managed by a single clinician in circumstances that include: (1) a sophisticated, high-volume trauma system; (2) responsibility for severe, high-energy injuries, often in multiply injured patients; (3) institutional protocols directing upper extremity injury to an individual responsible for all components of the injury; (4) the expertise gathered (acutely and in follow-up) by managing the resulting clinical load for over 30 years. Starting at the shoulder and extending to the digits, this work encapsulates the clinical experience in surgical philosophy, encompassing diagnosis, indications, and technical tips, including communication, OR preparation, surgical technique, and follow-up, delivered through the eyes of both a surgeon and an educator. Those familiar with this author's practice recognize the critical importance of consistency of approach and meticulous follow-up, so that lessons learned are based on fact, not war stories.

Those trained by this author significantly improve their clinical approach to upper extremity injury and are less intimidated by the most complex scenarios. Clinical opinions and indications expressed by the author may be debatable, but they are based upon a vast accumulation of experience. As presented, the topics in this work will be of value to those responsible for managing upper extremity injury, whether the clinician is on call occasionally or is specializing in upper extremity surgery with a high-volume trauma practice.

By emphasizing basics such as patient positioning and prepping technique, the author adds considerable value, defining that which should be basic and repeatable but is often the cause of the most confusion and wasted time when managing such injuries. This clinician's emphasis on doing it "the same way every time" regarding patient positioning, draping, surgeon/assistant positioning, and lighting position is often affectionately repeated by those trained by him, indicating an understanding of that philosophy brought to the management of complex injuries to maximize preoperative and perioperative efficiency and concentrate on debridement, surgical repair, and staging, if appropriate.

Those of us familiar with the author's practice have borne witness to Dr. Eglseder's style of clinical analysis, communication, and operative planning and execution, and have incorporated lessons learned every time we are confronted with a challenging upper extremity injury. His approach is at times unique, but it always reflects a pragmatic, creative, and, most importantly, *proven* approach to these injuries. The concentration of this experience and the lessons learned into this single work is a gift to all those who manage these injuries.

Professor, Department of Orthopaedic Surgery  
The University of Texas  
Health Sciences Center of Houston  
Houston, TX, USA

Andrew R. Burgess, Jr., MD

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## Preface

Echoes of “Eglsederisms” reverberate within the halls of the R. Adams Cowley Shock Trauma Center. Still, at the end of each year, I am faced with an ever-present flock of fellows with 3 × 5 cards (or, lately, some sexy phone gadget thing) trying to jot down my steps and algorithm for certain surgical scenarios that, it seems to me, have been endlessly repeated. It always intrigues me that despite the apparent note-taking, I will be advised about an upper extremity case that was treated without my being present and the fellow will say, “We did it exactly how you do it,” when, in fact, the case bears effectively no resemblance to my method. Throughout the years, hints have been dropped concerning the desirability of formalizing the sum of my surgical thought processes in a book, thereby obviating the need for the frantic 3 × 5 cards and phone notes. That time has come.

*Upper Extremity Trauma* formalizes the Eglsederisms and the steps I take in fracture care of the upper extremity. The chapters of this book are arranged by anatomic location, with each chapter briefly describing the thought processes involved in choosing surgical interventions and applied anatomy approaches, fixation selections, and techniques. Actual case examples and radiographs are included as appropriate. The reader should be advised that a number of these procedures are performed in the context of a multi-trauma setting, and some of the injuries, when isolated, might be treated nonoperatively.

I acknowledge the authors of cited references, but this book is not meant to be an exhaustive review of existing literature or anatomy. Rather, its focus is aimed toward the previous studies I feel pertinent to my development of techniques, as well as to my personal experiences. If a worthy work has been missed, the exclusion harbors no ill intent. It is also possible that, occasionally, a particular technique might not be properly referenced, making it seem as though the technique were solely my idea. To those who find this offensive, please note that the door swings both ways.

There is a growing use of “validated patient outcome” scores or studies intended for validation or justification, and not as indicators for surgery or treatment. I have great concerns regarding such studies that show a difference in results—results that might require years and large numbers of patients to demonstrate superiority of operative versus nonoperative treatments or of one technique over another. Common sense, seasoned clinical experience, and historical perspective seem to be left dying in the dust. A case in point is the mushrooming number of clavicles being subjected to open reduction and internal fixation.

I have seen written a number of times that a validated instrument used to compare two techniques might not be sensitive enough to detect a clinical difference. Really? Did you just say that? Consider that if it is not sensitive enough, perhaps it is because there really is no difference. Stop trying to come up with something just to support an opinion.

Within the following pages, you also will find references to a few unpublished projects thought to have valid outcomes but not yet formalized as peer-reviewed articles. I do not claim uniqueness or proprietary rights, or claim that I am presenting the definitive approach. This book is simply meant to offer guidelines that obviate the need for 3 × 5 cards and electronic note-taking gadgets.

Baltimore, MD

W. Andrew Eglseder, Jr., MD

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## Acknowledgements

I may have “written” this book but it didn’t just happen by itself. I want to thank the many people who helped me pull this off. Please realize that “thanks” isn’t adequate, and if I left someone out, I’m sorry:

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Finally, my kids and wife, Krystal, Elise, Ryan, and Evan. Thanks for putting up with having a doctor as a father. And Kate: “We did it”—first dissertation; then the book; time to refocus.

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## 1.1 Key Concepts for the Operating Room (O.R.)

Eglsederisms, as they've come to be known at Shock Trauma, express key dos and don'ts of operating room etiquette and protocol. The following are the top 35 reminders and rebukes that surgical students can count on hearing from their mentor.

### 1.1.1 Routine Facilitates Case Flow

We do it the same way every time. Having a routine facilitates the flow of the case, particularly for frequently performed types of cases, such as arthroscopy, ankle ORIFs, or vascular repairs.

### 1.1.2 Put Your Supplies on the Table

Don't use the patient as a table. Whether the patient is asleep or not, whether you are preparing a patient for surgery or changing a dressing in his or her room, don't put the dressing or draping supplies on the patient, because it is rude to use the patient as a table.

### 1.1.3 Avoid Cross-Contamination by Keeping a Neat Field

Be neat. Orthopaedic surgeons seem to take pride in a sloppy field. This can lead to cross-contamination, particularly in an infected or debridement scenario, where the debrided tissue can be put back into the open wound with a dirty sponge or sucker tip. Don't take the sucker tip from the wound and put it into an irrigation basin and then back into the patient.

### 1.1.4 Do Not Contaminate the Scrub Tech's Mayo Stand

The scrub tech doesn't come and shit on your coffee table. Don't take debrided tissue material and place it on the Mayo stand. Put it in a sponge and do not mess up the scrub tech's Mayo stand.

### 1.1.5 Clean Up Your Own Mess

Is your mother going to take away the Chux? Don't have someone clean up after you. If you put down pre-drapes, such as Chux, during your pre-prepping, clean up afterwards.

### 1.1.6 You Should Know This Already

That should be intuitively obvious. Enough said.

### 1.1.7 Pay Attention to the Warning Inside Your Head

If a little voice goes off in your head, listen to what it is saying. For example, if you have a draining wound and something inside of you says, "I should take that back and wash that out again," take it back and wash it out again. I have rarely seen anybody regret doing that.

### 1.1.8 Shine the Operating Room Lights Over Your Shoulder

Light doesn't shine through your head. Put the operating room lights over your shoulder, not behind your head. It amazes me how residents and fellows think that a light behind the head facilitates visualization of the operative field.



### 1.1.9 Be Prepared to Think Outside the Box

That's not orthopaedic—that comes from building shit in your garage. Sometimes, you need to think outside the box for how to accomplish something.

### 1.1.10 Don't Just Stand There

Surgery is not a spectator sport. If you are not operating, don't just stand there and sulk. Do something: Retract. Adjust the lights. Suction. Be involved. Think ahead. If you were the surgeon, what would be the next step? Thinking ahead will allow you to help.

### 1.1.11 Anticipate the Next Step

Think about the end of the operation at the beginning of the operation. Think about the next operation as this operation. Anticipating the next step will facilitate the flow of the case as well as help the scrub tech give you the appropriate instruments.

### 1.1.12 Focus Yourself

Use the Force.

### 1.1.13 Keep Things Moving

Let's not make a career out of this one case. Learn how to move and make progress.

### 1.1.14 Do Not Dawdle

Come on! We're not playing mah-jong. Do not dawdle.

### 1.1.15 Properly Align the X-ray C-arm

Do not look sideways—you *are not a fish*. Adjust the X-ray C-arm so that the image is properly oriented (i.e., straight up and down), so that you do not turn your head to orient the picture in your brain. This simplifies looking at X-rays.

### 1.1.16 Keep Your Movements Steady and Sure

Don't be impetuous. Move, but do not be spastic.

### 1.1.17 Don't Repeat What Doesn't Work

If Plan A does not work, do *not* do Plan A again. Doing something over and over and expecting different results is the definition of insanity.

### 1.1.18 Let Me Haunt Your Dreams

I hope you wake up at night with my voice screaming in your dreams. *Something* has to make an impression, an impact.

### 1.1.19 Before You Look at the Wound, Prep the Patient

Set up and pre-prepare the patient before you open and look at the wound. Do not expose the wound to us, and us to the wound.

### 1.1.20 Do Not Make Easy Hard

This isn't supposed to be the hard part of the case. Do not make the easy steps screw up progress.

### 1.1.21 Remember These Simple Steps

Normalize to the bone, not the plate. The plate pulls down to the bone. The screw will not sit flush if drilled at an angle.

### 1.1.22 Use Economy of Motion to Gain Speed

Move with speed and alacrity. Use economy of motion in the operating room.

### 1.1.23 Don't Add Errors to Errors

Don't make a compendium of errors. If one reduction step is off, and then the next, you are destined for a disaster of a final reduction result.

### 1.1.24 Think About How the Body's Designed

Teleologically speaking ... For example, the body ... Put the dominant digital arteries on the inboard side of the fingers.

### 1.1.25 Keep Clean Tools in Hand

Work with a clean tool. Clean instruments cut better.

### 1.1.26 Access and Adjust Fixator Nuts and Bolts the Easiest Way

Always keep your nuts out. Position external fixator nuts or bolts outboards; keeping them laterally positioned makes accessing and adjusting them easier.

### 1.1.27 Use Your Senses in the O.R.

Sense the operating room. Always be aware of what is going on. Listen to the anesthesia machine and pay attention to the nurses and scrub conversation. For example, “We are down to our last 16 mm screw.” Tell them to get another set.

### 1.1.28 Don’t Be a Brute

What do you think this is—Russia? Don’t be brutal and rough.

### 1.1.29 Finesse Your Surgical Techniques

Were you raised and trained by a pack of wolves? Use some degree of finesse in your surgical technique.

### 1.1.30 Have Your Fixation Devices at The Ready

The first reduction you get is your best. Don’t do multiple reduction maneuvers and then hold or wait for your fixation

device, K-wire, or screw. Have everything ready. Then do your reduction.

### 1.1.31 Visualize the Fracture

You are not always going to have drawings on the wall. See the fracture put together in your head.

### 1.1.32 Be Sure Each Step Has a Purpose

That’s like kissing your sister. Don’t do steps that lead to nothing, that don’t facilitate the case.

### 1.1.33 Don’t Double K-Wire Error

Don’t make two mistakes out of one. Say, for example, you put in a critical K-wire that’s not perfect—yet it’s holding. Don’t reflexively pull it out, lose reduction, and start over. Leave the first K-wire and position a second K-wire.

### 1.1.34 Know That the PIN Goes Through the Supinator

That just tells me you don’t know two things. When I ask a question, such as “What runs through the supinator?” and I get “median nerve” as an answer, that tells me you do not know that the PIN goes through the supinator and also that you do not know that the median nerve goes thru the pronator teres.

### 1.1.35 Don’t Expect Total Calm in the O.R.

Don’t get emotional. Keep an even temperament in the operating room.

## 2.1 Preparing the Operating Room for Surgery

The necessity of this topic may be questioned: Why would someone need to discuss getting the operating room ready for surgery? I would like to reiterate that this book is focused toward operative intervention, with the acknowledgment that the vast majority of orthopaedic injuries are treated nonoperatively.

What follows is a series of steps I routinely repeat to residents and fellows who either have not listened to previous attendings, were not taught by previous attendings, have not been able to think through the processes outlined here, or simply did not integrate basic awareness during their upbringing.

### 2.1.1 Help the Patient Make Their Own Treatment Decision

When obtaining the informed consent, there are a few “rules.” Though I don’t want to belabor the issues about informed consent and counseling your patient about the upcoming intervention, I do point out to residents that I never personalize my guidance and choice of treatment or surgical options. Frequently, a patient or family will ask, “What would you do if this were you or your brother/sister/mother/father?” I never answer that question. Given that each patient is unique in his or her needs, experiences, and expectations, I provide information, options, projected risks, and benefits. I might be asked, “In your professional opinion, what do you recommend?” This is a query that intrigues me, as I am unsure just what the patient or family thinks the preceding counseling was based upon. When asked this question, I circle back to the previous discussion of the injury, options, risks, benefits, and complications, and I make sure the patient makes his or her own decision.

### 2.1.2 Arrive on Time for the Procedure

Be on time for the operating room. Do not have the patient and the OR staff waiting for your arrival. It drives me crazy to hear residents say, “*Oh—nobody paged me to the OR.*” I can’t remember the last time I was paged to the OR for my case. I acknowledge that there are academic responsibilities as well as floor work, but I can pretty much guarantee that when private practice starts, you will be clawing at the door trying to get your cases started.

### 2.1.3 Prepare the OR Staff

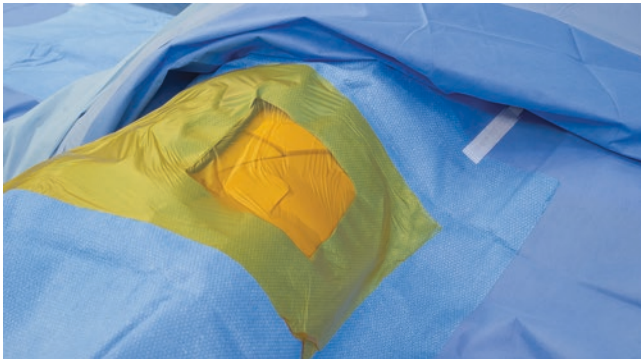
Review the case with the OR staff, particularly if the case is of a type not done on a routine basis. Though many centers, such as spine and joint centers, have a very methodical routine that may eliminate the need for this step, with a fracture case or in a trauma setting, preparation is very important. I frequently tell the surgical team that I have put the fracture together in my head and can see what equipment we need, but since people can’t crawl into my head, it is important for me to communicate. I review the radiographs with the staff. We go over the equipment that will be required, as well as the set-up of the room.

### 2.1.4 Set Up the Patient to Avoid Secondary Injury

Once the patient is in the OR and has undergone anesthesia (of whatever modality), it is important that attention is paid to what I call secondary injury. We are fortunate to have devices that allow extremities to be suspended (e.g., limbs are effectively in traction), which obviates the concern of telescoping the extremity, which might cause the fracture to shorten and potentially cause a nerve injury.

For cases requiring a graft of bone, skin, nerve, or vein, particularly from the leg, I set up the patient for ease of access and sterility. When harvesting bone, iliac crest, skin

from the thigh, or a nerve graft such as sural nerve, I use the opposite side (Figs. 2.1 and 2.2).



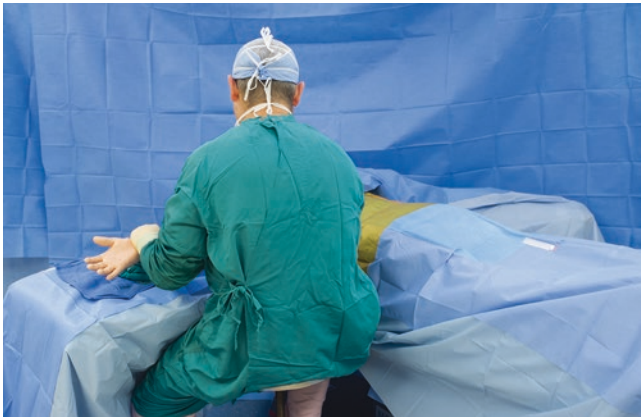
**Fig. 2.1** Iliac crest bone graft site draped



**Fig. 2.2** Arm and contralateral leg draped for possible skin, nerve, and bone graft harvest

A second team on the opposite side will have better

access; thus, fields are separated (Figs. 2.3 and 2.4).



**Fig. 2.3** Sitting adjacent to sterile field



**Fig. 2.4** Standing adjacent to sterile field

Otherwise, the operating surgeon, who frequently stands up and sits down, potentially contaminates the fields with his or her butt.

Vein graft is harvested from the ipsilateral leg because the operative harvesting surgeon typically leans over the contralateral leg, which is separated from the primary surgical site (Fig. 2.5).



**Fig. 2.5** Ipsilateral leg included in draping for vein graft harvest

### 2.1.5 Place the Tourniquet as High as Possible on the Extremity

If a tourniquet is to be used, it is important for the tourniquet to be placed as high as possible on the extremity (Figs. 2.6, 2.7, 2.8, and 2.9).



**Fig. 2.6** Proximal placement of tourniquet



**Fig. 2.7** Cast padding turned down to prevent tourniquet migration





**Fig. 2.8** Single edge-adherent, impervious clean drape over padding and tourniquet to prevent Betadine absorption



**Fig. 2.9** Absorbent barrier around tourniquet

This is true for a couple of reasons. One reason is that it allows access to the arm or extremity, so that the drapes do not block rotation or visualization. In the example of an arm, it is important for the profunda system to be occluded, and if the tourniquet is not placed high enough, there may be intraosseous bleeding, particularly in the pediatric population. If I am operating on the elbow, I use a sterile tourniquet but prefer not to use a roll-up type tourniquet because I am concerned about the potential for secondary injury from the telescoping extremity.

Also, when I am working on an arm or a hand, I place the hand table at the center of the shoulder to allow the arm to be positioned on the center of the table (Fig. 2.10).



**Fig. 2.10** Hand table centered on shoulder

This placement might seem obvious, but if I am not the one who places the arm table, I nearly always find the table placed closer to the axilla, with the arm falling off the top of the hand table (Fig. 2.11).



**Fig. 2.11** Hand table positioned too distal to arm

The hand table also must be positioned with a thought process regarding the use of a C-arm. If the elbow will be the center of the field, the hand table is placed more distally.

### 2.1.6 Properly Scrub and Drape the Patient

Once the pre-prepping is complete, I still prefer to use Betadine scrub. The scrubbing action is important because many patients come to us from the site of an accident and need mechanical debridement of detritus. When prepping and painting, work from the clean site out, but in an open or infected wound, paint from the clean or outside area into the open area. Draping is also an issue, as people tend to rush to put roll towels or address the arm, whereas the body or hand table should be addressed first so that the person doing the draping does not contaminate his or her gown.

Draping sequences demonstrated in upcoming chapters can be altered and individualized. Because certain surgical areas are approached via a similar vantage, not every chapter will include a draping sequence. Chapters 4–9 have specific draping nuances that will be discussed within each chapter. Chapters 10–14 encompass such fractures as humeral shaft and distal humerus T-intercondylar fractures, which are generally approached with the patient in a lateral position with a sterile tourniquet on the arm, and the arm on a padded Mayo stand, so Chaps. 11–14 refer to Chap. 10 for the draping sequence. Chapters 15–20 demonstrate fractures with elbow approaches. Generally, the patient is supine and using a sterile tourniquet; Chaps. 16–20 refer to Chap. 15 for the draping sequence. Chapters 21–28 demonstrate a supine position with a non-sterile tourniquet and with the arm on a hard table, except for Chap. 22, which includes a number of potential draping options. Chapters 23–28 refer to Chap. 21 for the draping sequence.

There are two facets of note: the absence of extremity drapes and the use of splits and the absence of stockinettes. Split drapes are used because a number of our patients have external fixators in place and the splits are easier to apply. Extremity drapes require stretching in order to get over the external fixation and can tear with stretching. A single system simplifies the stocking of the draping supply and can eliminate any mental gymnastics for nurses and surgical technicians attempting to figure out an answer to the question, “Is this an extremity drape or split case?”

In reference to the stockinette infatuation: The theoretical purpose of covering a previously dirty, contaminated foot or hand that has been sterile prepped and then covered with a stockinette to prevent an infection at a surgical site is

still unsupported. I am still waiting for even one case report to substantiate this position, but I personally know of four catastrophic complications that resulted from cutting off stockinettes. One incident included a near amputation of a small finger. Because I know of significant negatives with only theoretical positives, there are no stockinettes on my patients.

### 2.1.7 Marking Surgical Incisions

Incision outlining should be performed before tourniquet inflation, though bleeding may require the opposite sequence in the case of an open fracture. When I have a patient with an open injury, I try to incorporate the open component into the surgical incision (Figs. 2.12 and 2.13).



**Fig. 2.12** Anterolateral humeral incision incorporating open wound



**Fig. 2.13** AP and LAT radiographs of an open humerus fracture



If not, I use the standard approach and limit the skin debridement on the open site (Figs. 2.14 and 2.15).



**Fig. 2.14** Ulna incision including open dorsal wound

**Fig. 2.15** AP and LAT radiographs of open radius and ulna shaft fractures



Please use adequate incisions. Working through keyholes is one of the major problems in gaining acceptable access to the fracture.

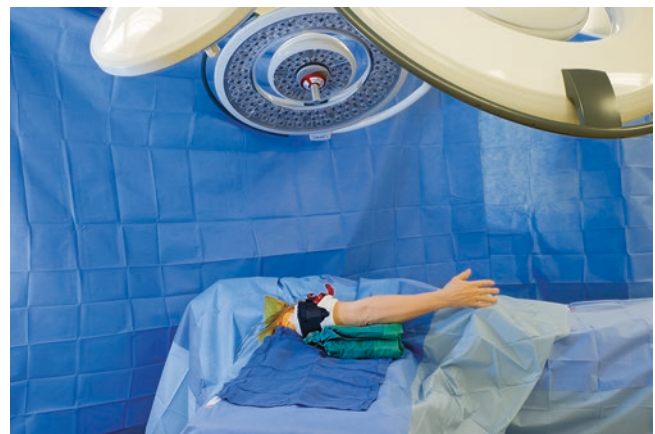
The lights should not be positioned behind anyone's head. The light should be over the ends of the table or over the surgeon's shoulders (Fig. 2.17).

### 2.1.8 Position the OR Lights to Shine Over Your Shoulder

Of utmost importance is light positioning. It astounds me how many residents and fellows act as if light shines through their heads (Fig. 2.16).



**Fig. 2.16** Operating room lights positioned behind the surgeon's head, which blocks the light



**Fig. 2.17** Properly positioned operating room lights. Lights are positioned over the surgeon's shoulder at the end of the table

The extremity to be operated on should be positioned in the center of the operating room for optimal lighting.

### 2.1.9 Do Not Block the Surgical Tech at the OR Table

Many people, particularly those in an academic setting, have a great interest in watching and being involved in the operation, but it is important not to block the surgical tech. The surgical tech must always have access to the field in order to appropriately pass instruments. I call the tech the second most important person at the table.

In the same spirit, I abhor hoarding or keeping instruments on the field, as instruments have the tendency to fall and not to be clean, and count issues may be caused for the staff. So always return instruments to the tech when they are not in use.

### 2.1.10 Do Not Spectate at the OR Table

As the years have gone by, I've seen a growing tendency toward passivity among surgical residents and fellows. I'm frequently heard to say, "Surgery is not a spectator sport." If you are not doing the surgery, try to anticipate the next step of the surgery. Either retract, adjust the lights, or help hold the arm still. Do something to be involved.

## 2.2 Principles of Operative Intervention

### 2.2.1 Work from the Known to the Unknown

One of the major principles in open fractures is always to work from the known to the unknown. This means that you should not try to work through the injury site. Extend your incisions, go to work in the known areas, and work back into the zone of the unknown and the injury. I effectively always use a tourniquet: The idea that the ischemia will cause more injury, I believe, is obviated by the ability to see the vital structures and to move with alacrity and speed through the debridement while being more definitive. To ascertain tissue viability, you

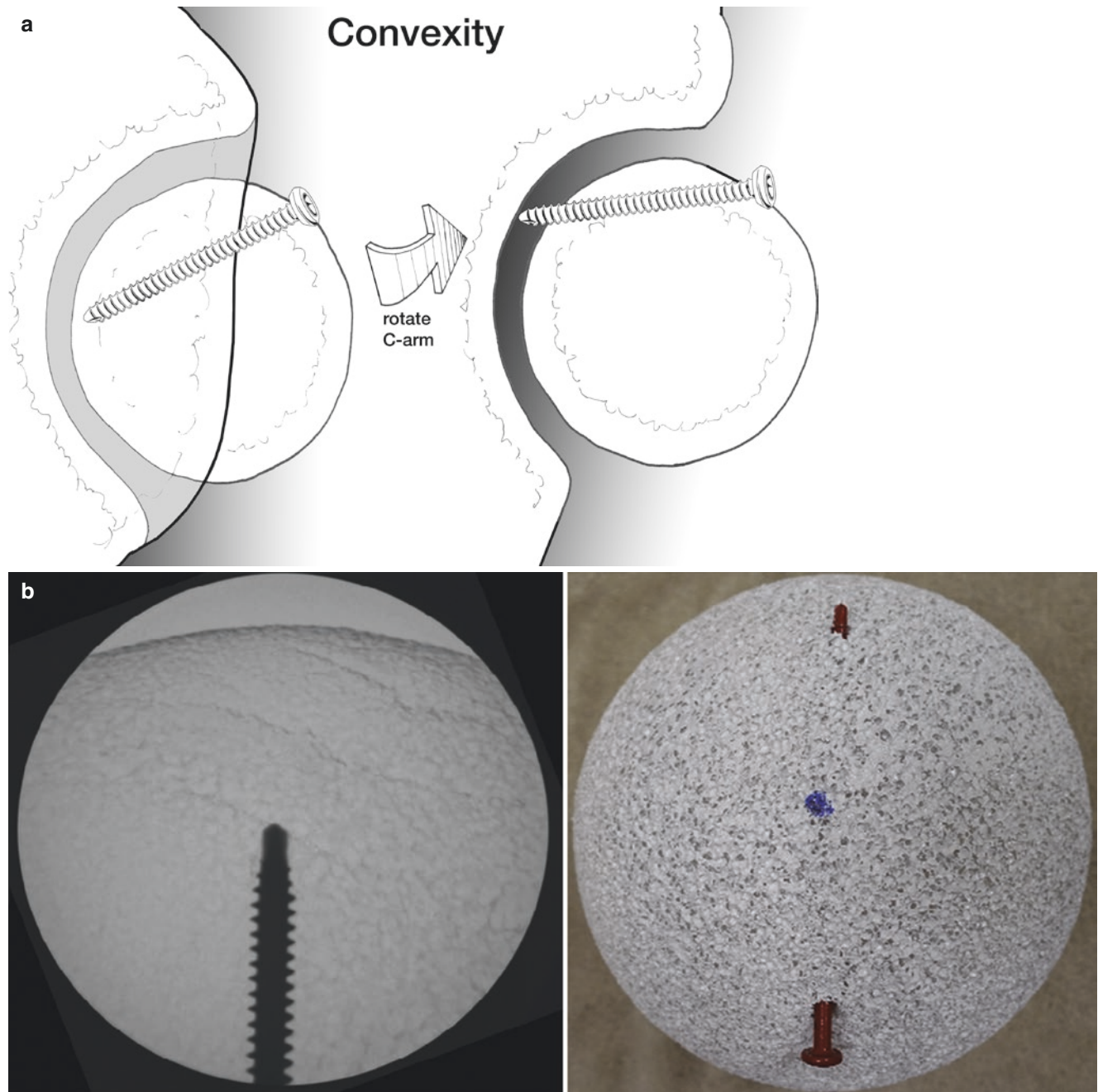
do not need to see bleeding tissue. Remember the four criteria for muscle viability: consistency, circulation (or bleeding), contractility, and color, with the last being the least important [1]. During the surgical approach, I prefer a covered cautery device from Bovie Medical Corporation (Clearwater, FL, USA) to help ensure that the surrounding tissue will not be damaged. When irrigation is being performed, I prefer to remove the sucker tip that was used in the wound in order to prevent it from being used to suck out any basin or other collecting device, thereby helping to avoid cross-contamination.

### 2.2.2 Fixation Principles

Fixation philosophy will be discussed in the Chap. 3.

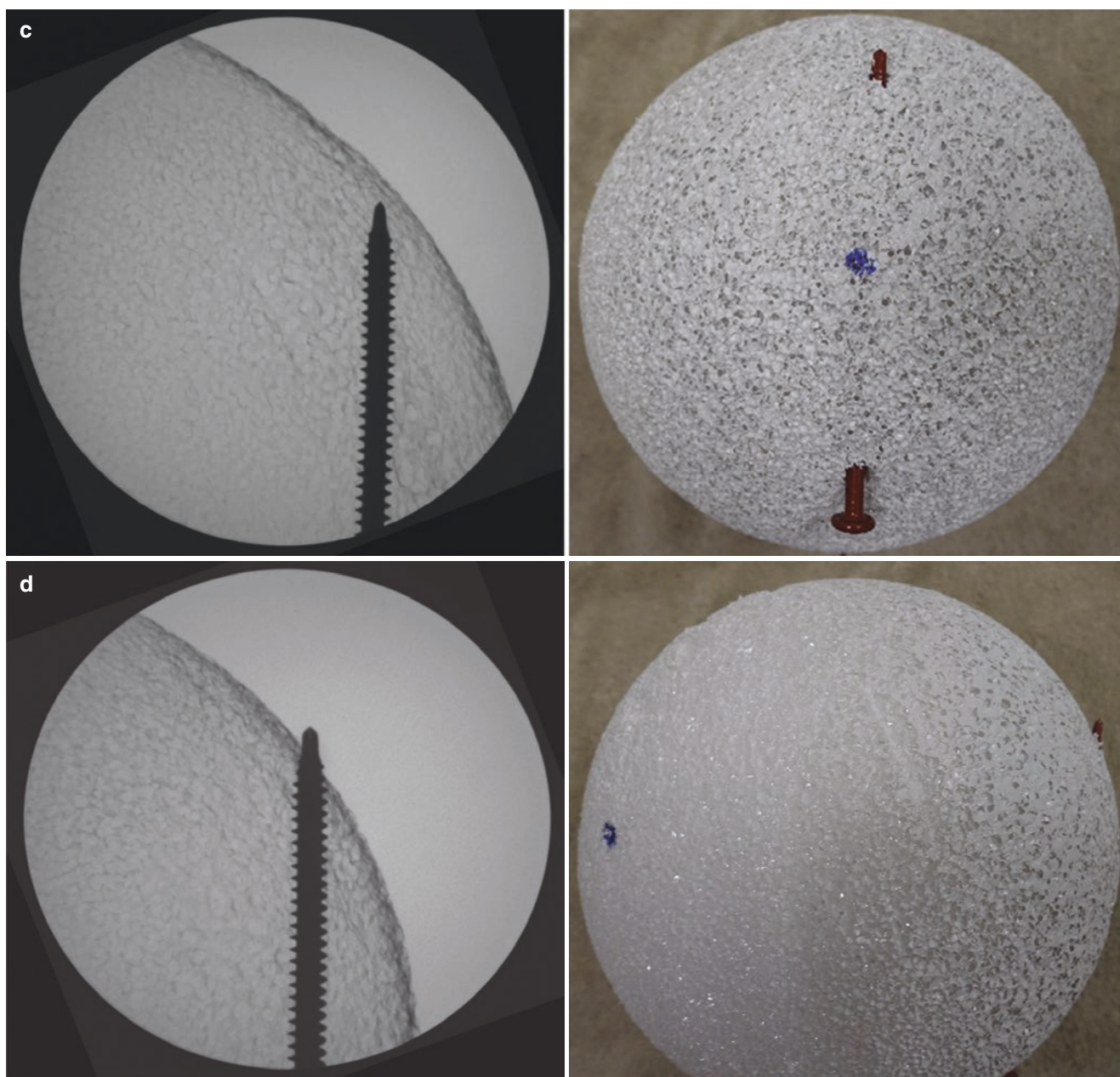
### 2.2.3 Get Intraoperative Radiographs ASAP

Intraoperative radiographs should be obtained as soon as fixation is completed, instead of waiting until the patient is the recovery room. Intraoperative films allow for fixation adjustment, screw length change, and identification of missed fractures. Waiting for the patient to be in the recovery room before taking X-rays may result in the need to re-anesthetize the patient for a second surgery, or it may lead you to rationalize a result that may not be optimal, with the hope "It will do fine." Radiographs should be evaluated and examined not only for reduction, fixation, and screw length but also for articular and periarticular fractures, which require a critical eye. Fixations around ball-and-socket or cup-and-saucer type joints, such as glenohumeral or radio-carpal joints, require particular appreciation of the convexity/concavity rules. Hardware penetration demonstrated on any view on a convex surface means "It's in the joint." On the other hand, clearance of hardware on any concavity view indicates that the hardware has not violated the joint surface ("The joint is not violated"). Using models as mock-ups, beginning with the convexity scenario, it is possible that two orthogonal views will have a fixation that appears not to penetrate, but when the X-ray is truly tangential, penetration can be seen (Fig. 2.18).



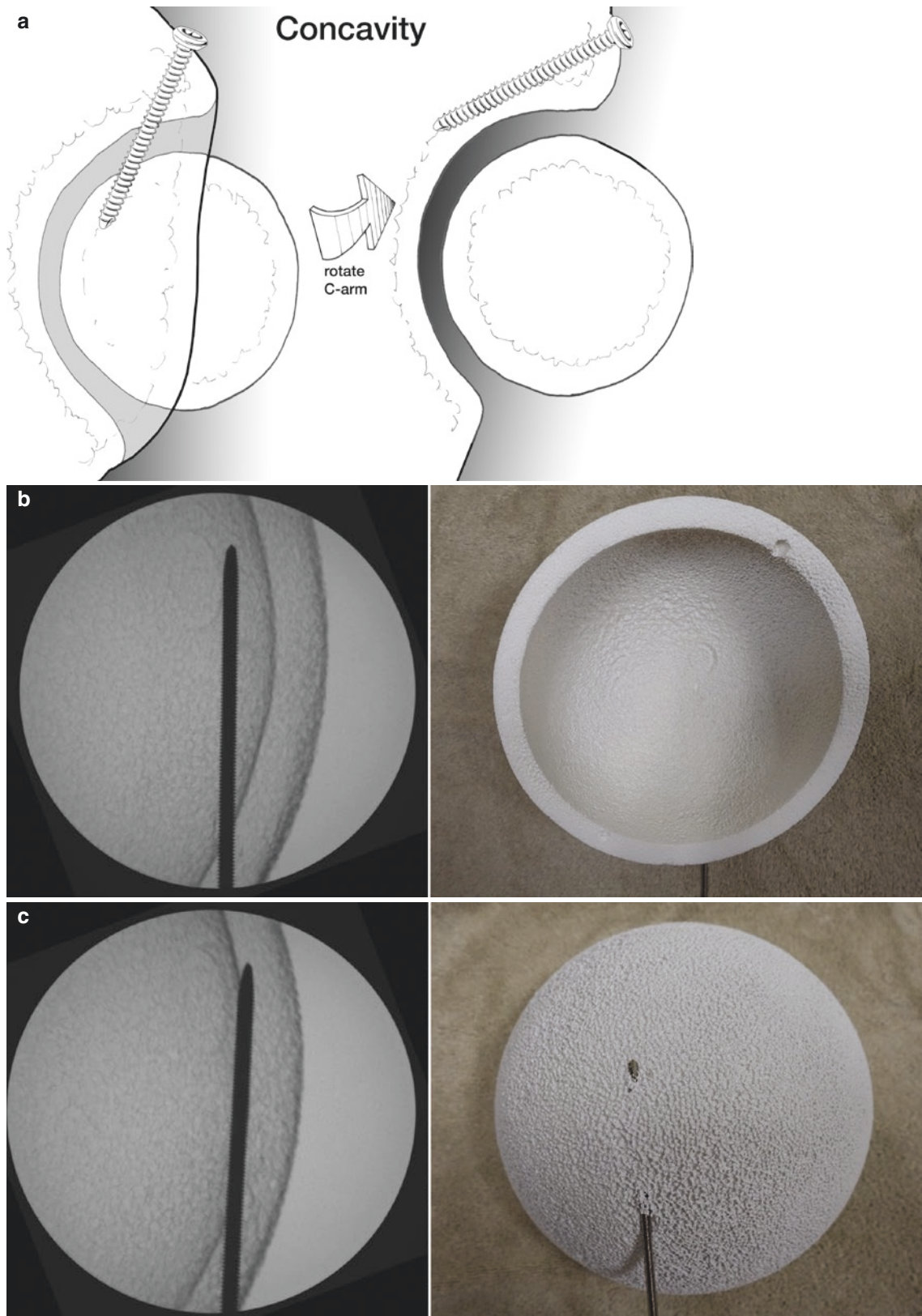
**Fig. 2.18** (a–d) Screw penetration demonstrated on tangential projection in convexity using Styrofoam mock-ups



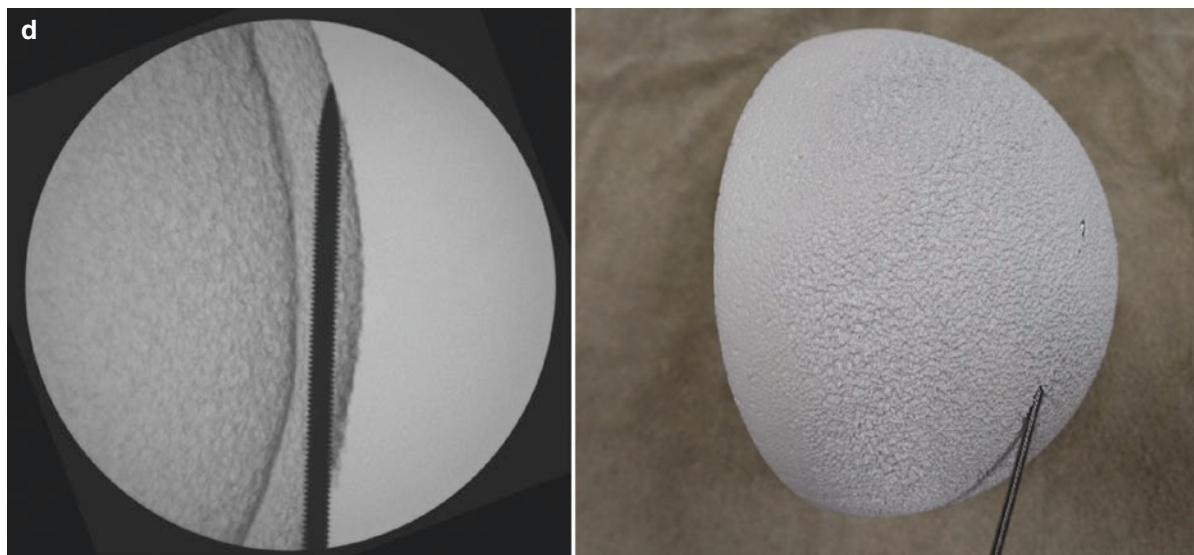


**Fig. 2.18** (continued)

Conversely, with concavity, a non-tangential view may appear to show fixation in the joint; yet, when truly tangential, it can be seen not to violate the joint (Fig. 2.19).



**Fig. 2.19** (a–d) Screw clearance demonstrated on tangential projection in concavity using Styrofoam mock-ups



**Fig. 2.19** (continued)

#### 2.2.4 Disallow These Words: “Squeeze My Hand”

Once the case is completed from the fixation standpoint, closure is carried out. I do very few deep closures. In most cases, I feel that once the skin is closed using proper approaches, the deeper planes will self-oblitrate and strangulating the deeper sutures or putting in braided sutures is not required. I position my drains to exit in the orientation that allows the end of the drain to be, as I put it, at the bottom of the well. Therefore, if a forearm is being addressed, the drain will exit distally because the arm is elevated and the tip of the drain will be placed at the bottom of the fluid collection. Splinting is paramount in the upper extremity, and it is critical that the splint is held until hard. The anesthesiologist needs to know the importance of allowing the splint to harden before the patient is either extubated or awakened. The patient’s arm must be held as the patient awakens from anesthesia. Discuss with the anesthesiologist the importance of not asking the patient to “squeeze my hand”—not even to squeeze the un-operated hand—because the patient may move the fingers on the operated hand, which may disrupt your surgery.

#### 2.2.5 Communicate Case Details to the Recovery Room Staff

At the completion of the case, never forget to interact with the recovery room staff regarding the operation’s important steps, particularly those areas that require staff monitoring, such as vascular checks or positioning of the extremity.

#### 2.2.6 Talk with the Patient’s Family

Finally, always talk with the patient’s family. I wait until the patient is extubated or has a controlled airway and is in the Post Anesthesia Care Unit. I take this position because I know of a patient’s demise between closure and attempted extubation, while the surgeon was talking to the family.

#### Reference

1. Scully RE, Artz CP, Sako Y. An evaluation of the surgeon’s criteria for determining the viability of muscle during debridement. *AMA Arch Surg.* 1956;73:1031–5. <https://doi.org/10.1001/archsurg.1956.01280060131029>.



### 3.1 Open Reduction and Internal Fixation

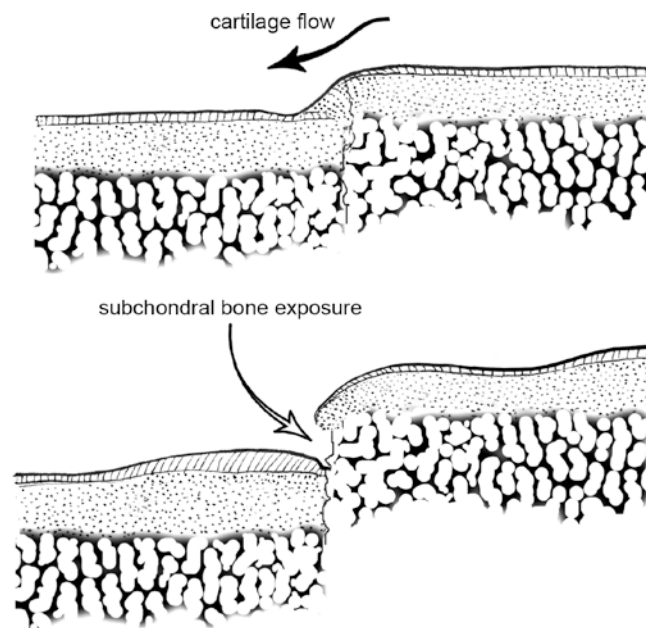
Put down the cell phone or whatever electronic gizmo you're playing with and go out into the garage and build something. The specialty you've selected is very demanding of psychomotor skills, including hand/eye coordination, and there are principles in stabilization or fixation that apply both to building a cabinet and to fixing an ankle. The focus of this chapter is open reduction and internal fixation, allowing that some isolated cases may be treated nonoperatively. However, when internal fixation is selected, various principles should be reviewed and reinforced. These "principles" are not necessarily fracture-specific, nor are they professed to be unique or novel. Some have a scientific basis. Some are my personal opinion. But the principles introduced in this chapter apply throughout the following chapters.

#### 3.1.1 Step-Off for Intraarticular Fractures

A major focus of operative intervention is joint realignment and fixation. For intraarticular fracture, my driving principle is the assumption that the amount of step-off that can be tolerated is predicated upon articular cartilage thickness. Once the subchondral bone is exposed, the potential for articular cartilage damage is present. A review of tibial plateau fractures by Moore *et al.* [1] reports the idea that the intraarticular step-off tolerance should not be greater than the thickness of the articular cartilage. This clinical observation was offered without scientific support, however.

Llinas *et al.* [2], examining intraarticular step-off in a rabbit model, found that the cartilage remodeling potential significantly decreased once the articular cartilage thickness

had been exceeded with exposure of the opposing cartilage to subchondral bone (Fig. 3.1).



**Fig. 3.1** Diagrammatic representation of cartilage changes in step-off less than and greater than the cartilage thickness

Residual incongruity was less in the group with less than full-thickness step-off. Cartilage changes, such as fibrillation and thinning, were greater with full-thickness step-off, as well as with joint contact pressure alterations. A leap-of-faith clinical assumption is that a step-off greater than articular cartilage thickness in a joint may, in fact, lead to an increase in subsequent arthritis, as proposed by Moore *et al.* [1].

3.1.2 Step-Off and Subsequent Articular Development

Knirk and Jupiter were among the first to study intraarticular step-off and subsequent articular development in the upper extremity [3]. Their findings are frequently interpreted to mean that greater than 2 mm step-off is not tolerated in the distal radius, but if one delves into the study, a different conclusion may be drawn: Their paper demonstrates that less than 1 mm of step-off is associated with only an 11% incidence of arthritis in the distal radius fractures. When the step-off is greater than 1 mm, the incidence of arthritis significantly increases (Table 3.1).

Table 3.1 Amount of step-off resulting in arthritis<sup>a</sup>

Step-off (mm)	Radiographic arthritis (n (%))	
0–1	2/19 (11%)	
1–2	14/16 (87.5%)	22/24 (91%)
2–3	8/8 (100%)	

<sup>a</sup>Data from Knirk and Jupiter [3]

This can be correlated with a paper by Pollock *et al.* [4], which demonstrates that the joint cartilage at the distal radius is approximately 1 mm thick.

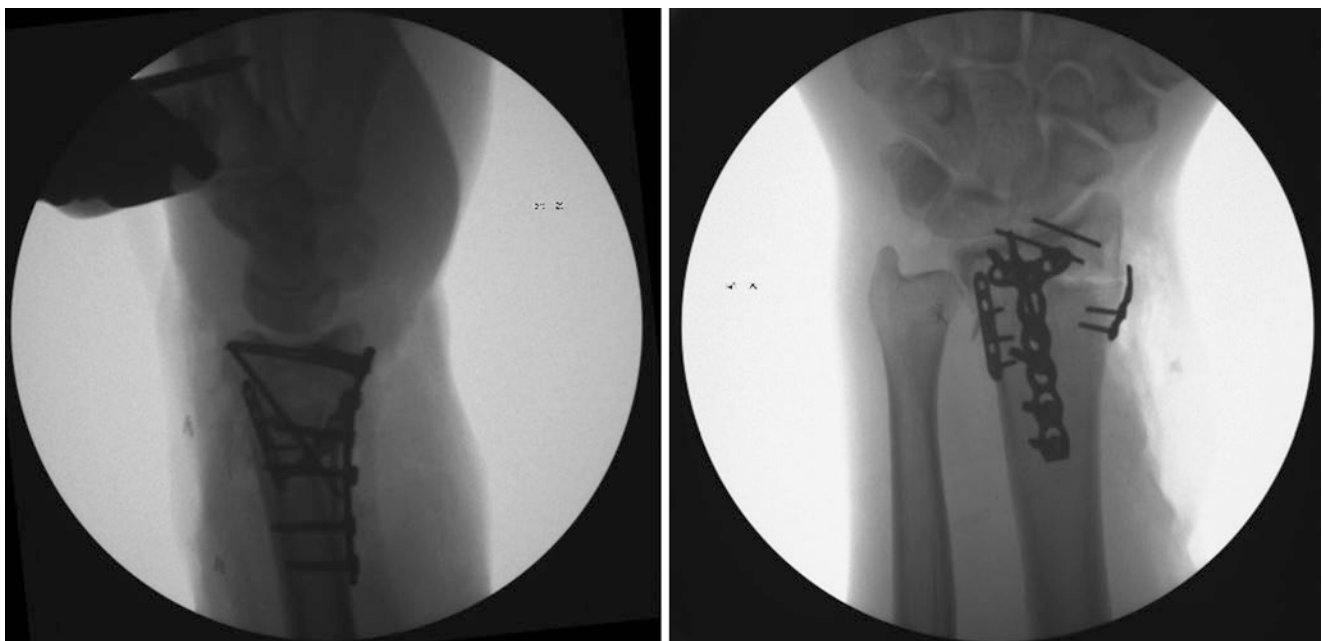
Referring back to articular cartilage of the distal radius, one would like to project that 1 mm thickness in the distal radius cartilage would equate to the finding of Knirk and Jupiter [3], that with less than 1 mm step-off, only 11% of patients developed arthritis. If one appreciates the thickness of the glenoid or patella and relates this to a step-off with acceptable functional outcome, we can see that joint step-off tolerance somewhat holds throughout the body. The thicker the cartilage, the more step-off is tolerated.

3.1.3 Primary Clinical Objectives: Bone or Enchondral Healing?

Two questions need answers: First, what is the correlation of radiographic arthritis with clinical symptoms? Radiographic arthritis is not necessarily correlated with poor clinical results (Figs. 3.2, 3.3, 3.4, and 3.5) [5, 6]. Second, what are our abilities to determine step-off?

**Fig. 3.2** Distal radius fracture with poor radiographic result following open reduction and internal fixation (ORIF). The patient underwent subsequent hardware removal and debridement for osteomyelitis. The patient became nearly pain-free and returned to manual labor (*see* Figs. 3.3, 3.4, and 3.5)



**Fig. 3.3** Traction radiographs**Fig. 3.4** Intraoperative radiographs



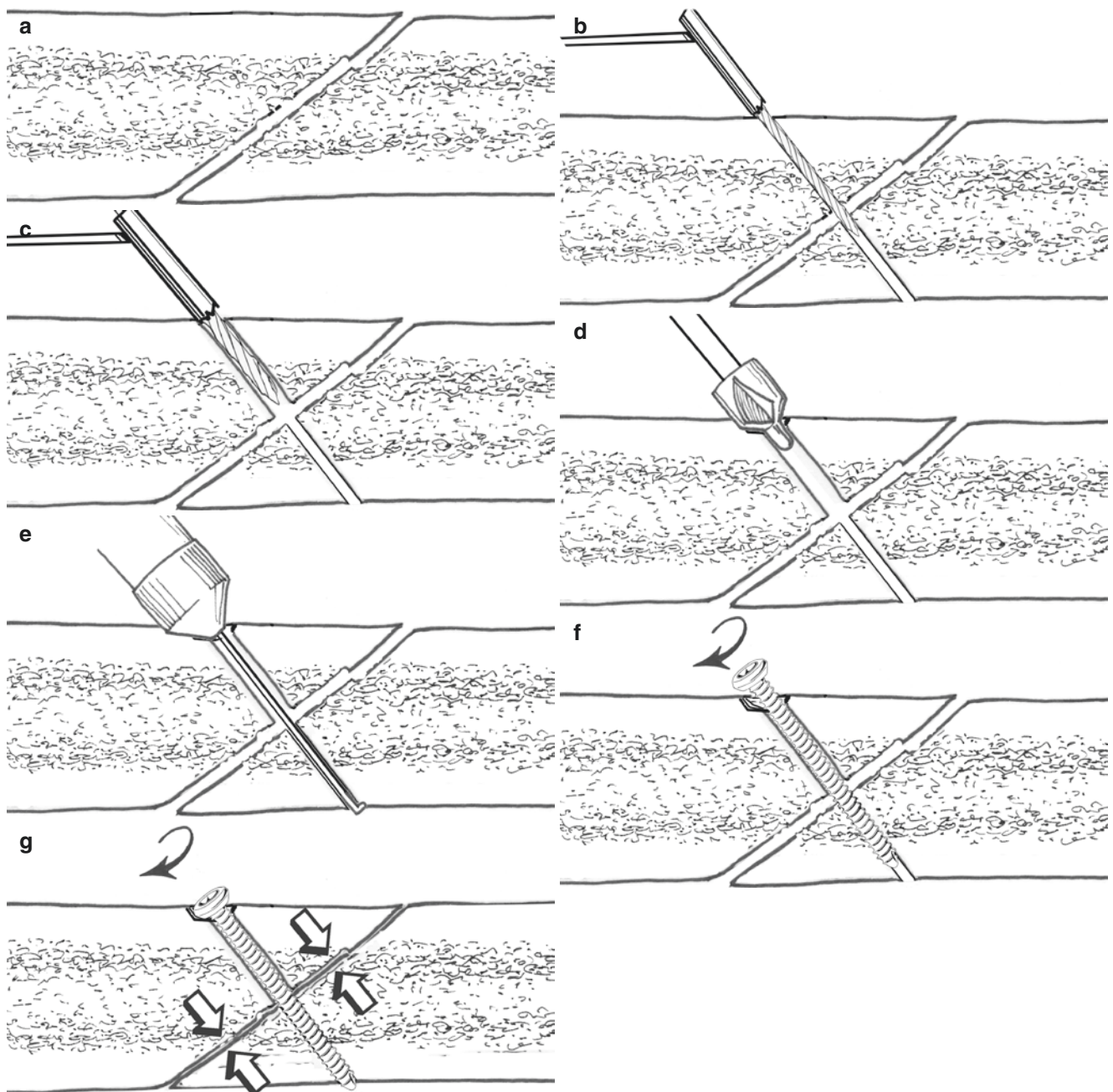
**Fig. 3.5** Radiographs at time of discharge

Determining step-off in the distal radius is very difficult to delineate and elucidate on plain films or even with fluoroscopic evaluation. A CT scan is superior to either method [7, 8, 9].

When internal fixation is considered, one must determine whether the objective is primary bone healing, such as in the diaphyseal region, or enchondral healing in the metaphyseal region. Diaphyseal bone that is being approximated with compression for primary bone healing needs to have a stable construct to allow the appropriate forces across the fracture to allow the cutting cones to cross the fracture and allow subsequent healing. The issue about metaphyseal bone in certain fixation modalities and the need for greater compression from one device to another must be questioned. Metaphyseal bone heals more by enchondral bone healing, and while there is need for stability, compression is not as critical as bone opposition. In fact, attempts at increasing compression may lead to crushing of the metaphyseal bone.

### 3.1.4 Lag Screw Techniques

Lag screw fixation and lag screw techniques are some of the first aspects of internal fixation that “youngins” are probably taught, but I do not use or teach the “classic” standard technique of the glide hole followed by the pilot hole. I actually flip these two steps: I drill the pilot hole first, then the glide hole, and then I over-drill the glide hole. Here’s why: When dealing with small bone fragments, particularly in the hand and upper extremity, I find it easier to site and drill the smaller, farther fragment with the smaller bicortical drill bit to assure purchase of a far cortex. I acknowledge that this technique requires its practitioner to drill the pilot and glide holes in a collinear manner, and practitioners may have difficulty maintaining a collinear relationship when over-drilling. There once was a device that allowed pilot hole drilling in the far fragment followed by hook guide placement in the pilot hole, which then allowed the glide hole to be over-drilled in the near cortex. This is not practical in very small bone situations. The sequence I use is to drill the pilot hole, drill the glide hole, then countersink and gauge the depth (Fig. 3.6).

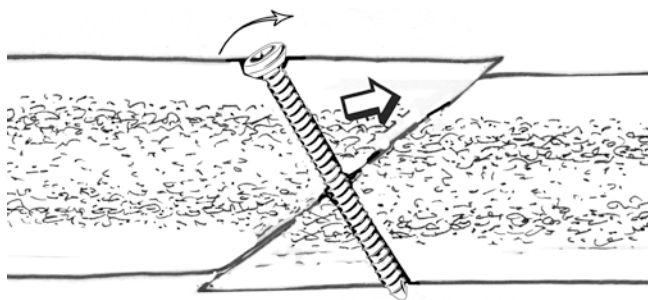


**Fig. 3.6** Lag screw technique. (a) Oblique pattern amenable to lag fixation. (b) Pilot hole drilled. (c) Over-drill near cortex. (d) Countersink. (e) Measure. (f) Insert screw. (g) Compression across fracture-osteotomy



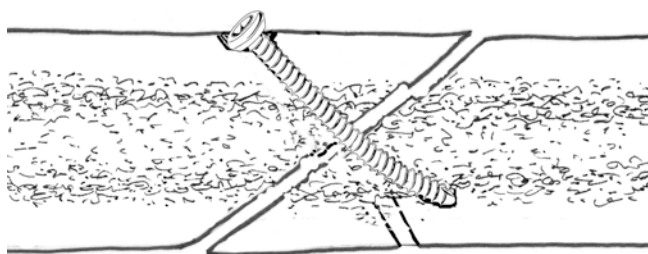
Countersinking followed by measuring allows for a more precise assessment of depth where any protrusion would potentially impact tendon gliding, particularly with phalangeal fractures. After countersinking, measure, then follow with screw insertion.

Threaded lag screws, when placed obliquely, tend to normalize to the long axis of the bone; the threads then engage one side and block some potential compression (Fig. 3.7).



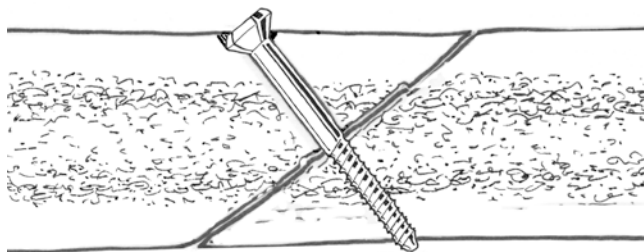
**Fig. 3.7** Possible shearing and displacement when using a lag screw

However, if a lag screw is placed in a manner too oblique to the long axis of the bone, it may tend to skip down the bone's endosteal surface (Fig. 3.8).



**Fig. 3.8** Screw glancing down canal, giving impression that fixation has occurred

To avoid this possibility, you may want to drill at less than a 90° angle to the fracture. This will allow the lag screw to be inserted slightly more perpendicular to the long axis of the bone. Another option is to tap the far cortex to ensure engagement with the screw. In addition, some 3.5-mm systems offer a shaft screw with the near-shaft portion of the screw equal to the glide hole; this increases compressive forces up to 60%, according to Synthes® [10] (Figs. 3.9 and 3.10).



**Fig. 3.9** Shaft screw used to avoid near fragment thread engagement despite over-drilling

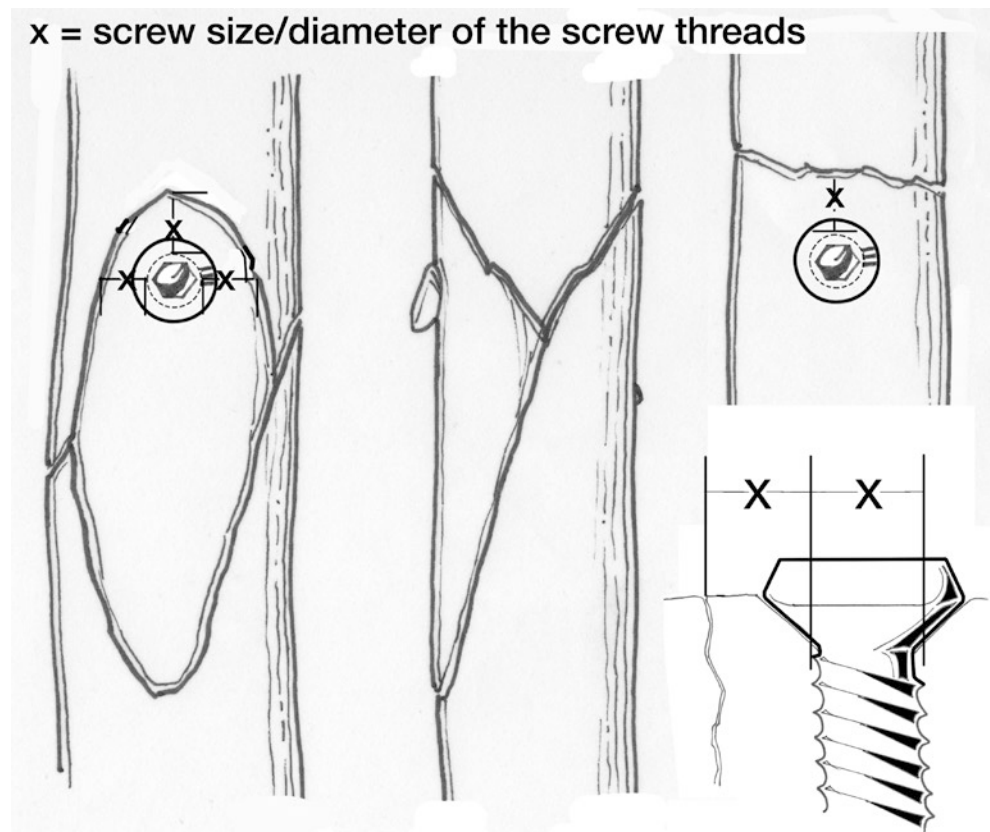


**Fig. 3.10** Shaft screw, note proximal portion equal in diameter to threads, this is not a partially threaded cancellous screw

### 3.1.5 Required Amount of Bone for Fixation

Another consideration too frequently unappreciated with lag screw fixation is the amount of bone needed to surround the screw when working with butterfly fragments or oblique fractures. My rule of thumb is that the amount of bone surrounding the screw hole should be equal to the size of the screw in all its dimensions. Therefore, if you have a butterfly fragment 6 mm in width and you are using a screw no bigger than 2 mm in size, the fragment needs to have 2 mm of bone on each side, with 2 mm of bone surrounding the screw (Fig. 3.11).

**Fig. 3.11** Bone requirement around the lag screw to prevent it from splitting or fracturing the bone



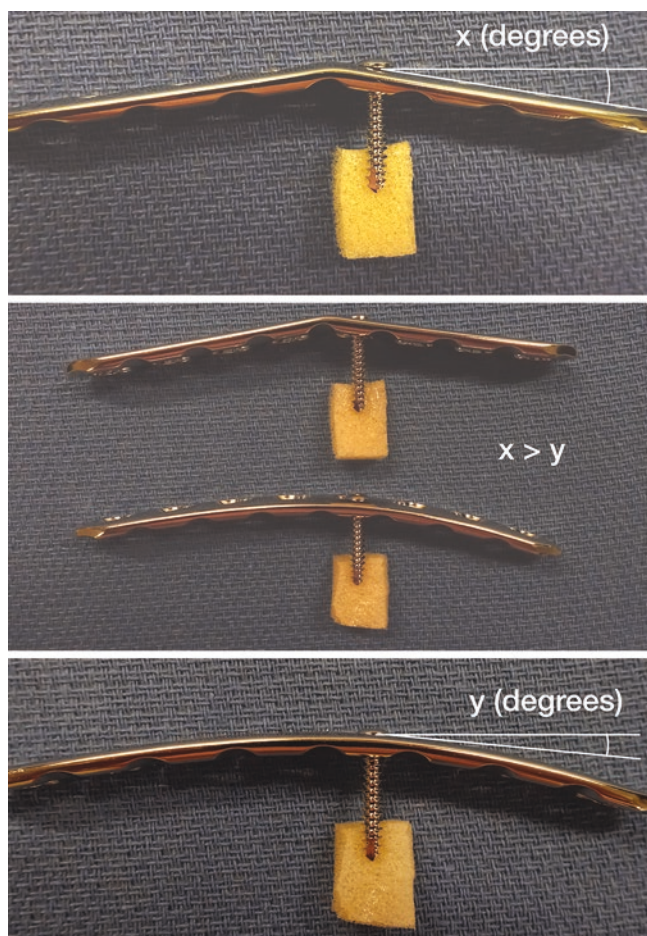
### 3.1.6 Torsional Strength Reduction

Work has been done examining metastases of the femoral cortex and the torsional strength reduction consequent to the defects created. It is known that a 20% defect that increases stress may cause a 34% decrease in strength [11]. Harrington [12] advocated prophylactic fixation of femurs when more than 50% of the femoral cortex involved lytic lesions. Finally, Brooks *et al.* [13] (citing Bechtol *et al.*) demonstrates that tension strength becomes significantly decreased when the hole in the bone exceeds 30% of the diameter. I use these principles to invoke the “thirds rule” (that is, the bone fragment needs to be three times the screw size selection). The AO-ASIF Group [14] advocates using the screw head size as the dimension for the surrounding bone, but I prefer to use the

screw size, as this represents the actual potential bone defect or hole size.

### 3.1.7 Pre-Stressing and Positioning the Plate

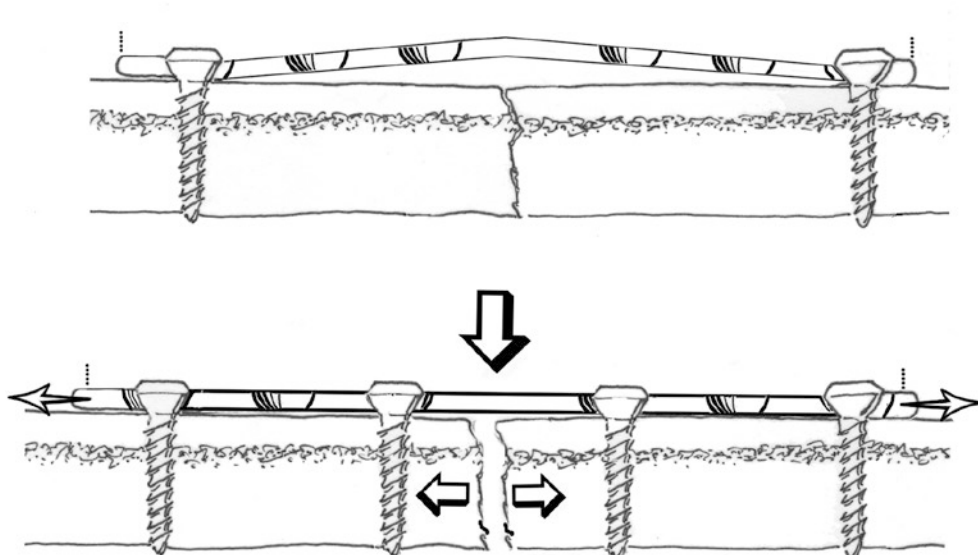
When using plate and screws to perform fixation, it is important to appropriately contour the plate. There should be adequate bony contact, not a large gap between the bone and plate in a non-locking construct. The AO-ASIF Group demonstrated that pre-stressing the plate is required to apply compression force on the far cortex. The plate bending should be acute, not a gradual bend, in order to subtend a greater head plate angle, thus increasing compressive forces [14] (Fig. 3.12).



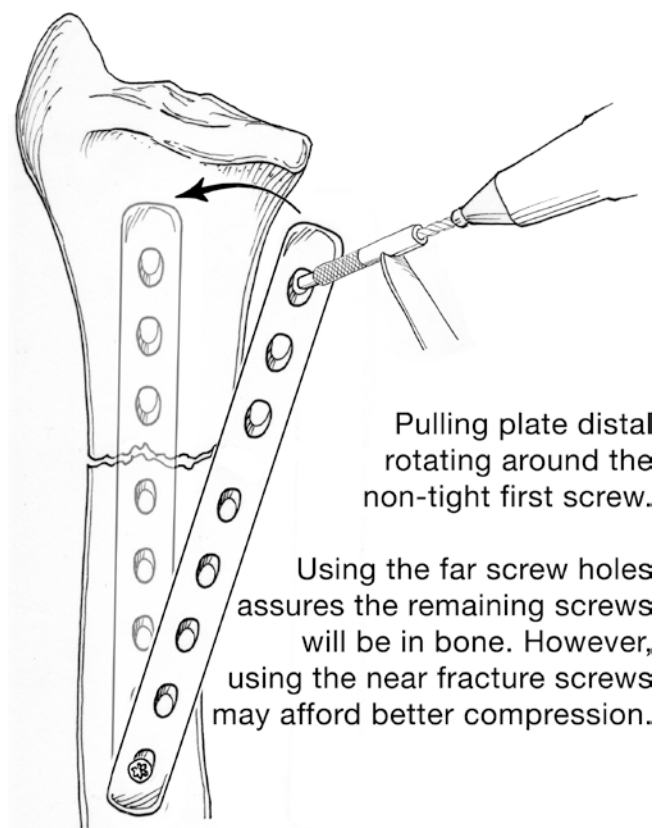
**Fig. 3.12** Acute bend versus gradual bend to create greater far side compression

Initial screws should be placed closer to the fracture rather than placed at the ends of the plate. Placing the far screws first could result in fracture distraction when the inboard screws are inserted (Fig. 3.13).

**Fig. 3.13** Distraction at fracture when placing inboard screws after far screws, if the plate is over-contoured



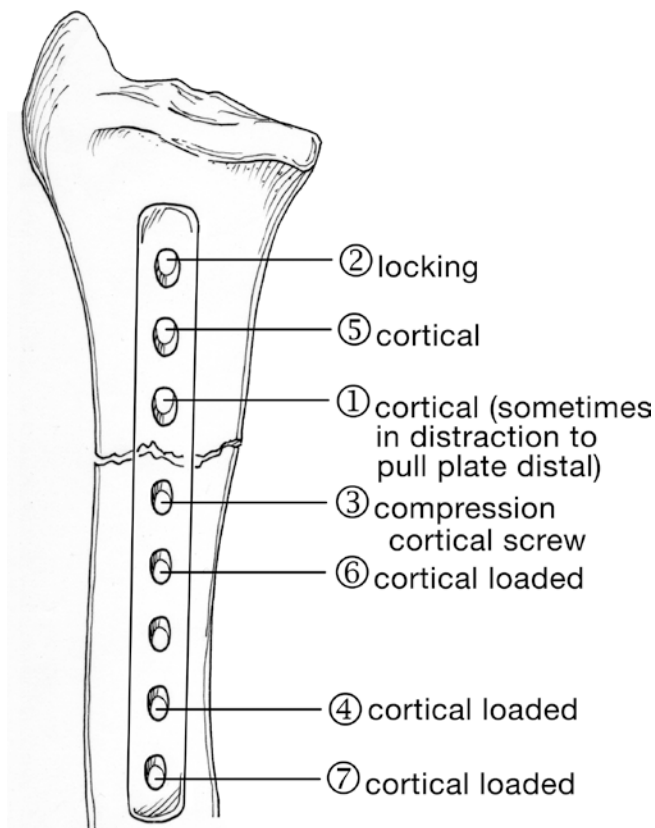
When initially positioning the plate, it may not be necessary to completely tighten the first screw if you have to adjust the plate at the other end of the bone. The second screw may be placed in compression in an eccentrically placed fashion (Fig. 3.14).



**Fig. 3.14** Plate pivoted around incompletely seated screw



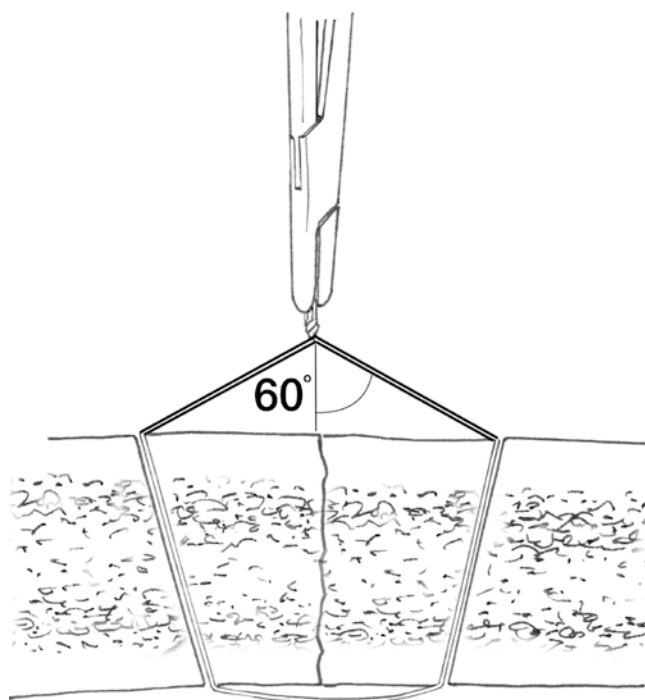
Another principle about compression and plating is where to begin the initial screw placement and what screw to compress with (Fig. 3.15).



**Fig. 3.15** Screw insertion sequence in fixation with a metaphyseal component

I prefer to compress in the better diaphyseal bone. For example, in a distal radius metadiaphyseal shaft fracture, I use a cortical screw next to the metaphyseal region close to the fracture, and follow with a locking screw in the more distal hole. I seat the first cortical screw, thereby giving the screw only one job, that of creating friction between the plate and the bone. A more proximal screw in the better diaphyseal bone will be used both to bring the plate down to the bone and to afford compression.

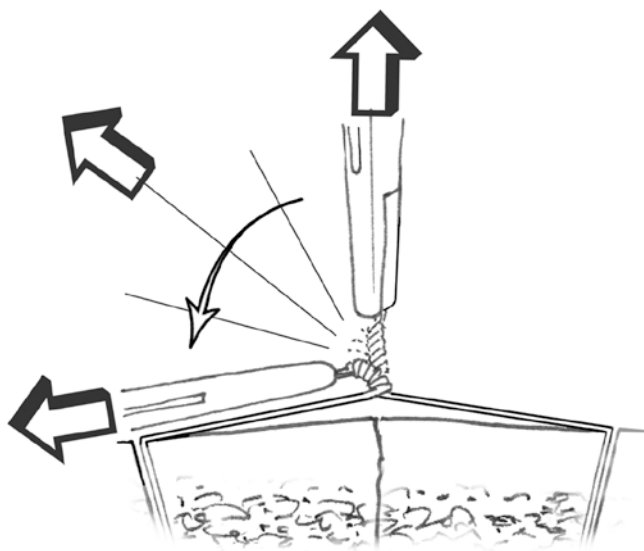
When I perform an ORIF in a comminuted fracture but desire some degree of compression, I frequently minimize the number of fragments until, effectively, there is but one remaining fracture complex. The modality used may be either mini-frag screws, mini-plates, or interosseous wires. When using interosseous wires for fragment number reduction or provisional fixation, I will use either 22-, 24-, or 26-gauge wire, depending on the fragment size. The technique is to pre-drill with a 1.1-, 1.5-, or 2.0-mm drill bit; pass the wires through the holes; and tighten by grasping the wires centrally in a symmetrical fashion, such that one wire twists around the other wire with an equal angle of both limbs (Fig. 3.16).



**Fig. 3.16** Symmetrical wire tightening

### 3.1.8 Twisting and Passing Wires

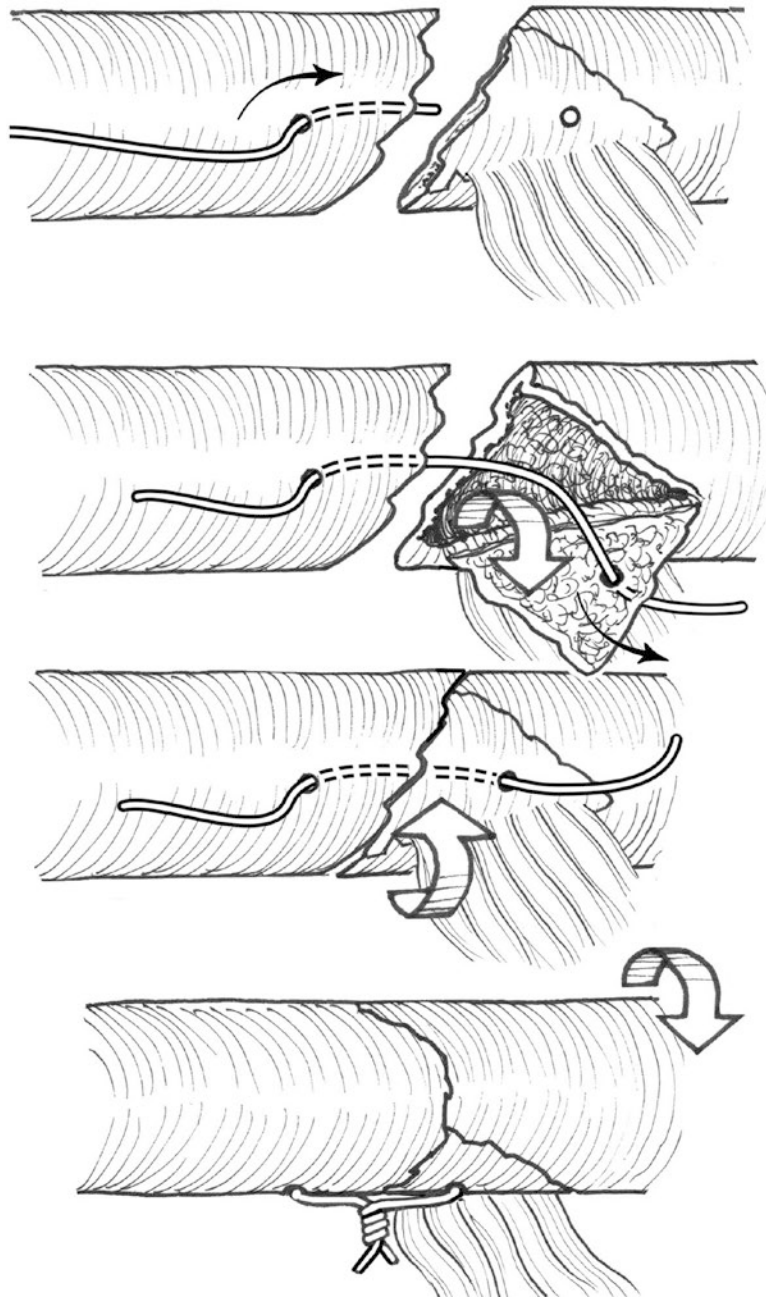
Various studies demonstrate that only two to three twists are required in the wire construct [15, 16]. The first half-twist gives about 66% of the overall system strength. From a practical standpoint, four twists are usually required to turn the wire down and to grasp it with the appropriate device. The final twist should be a turn down, still twisting to maintain some compressive forces (Fig. 3.17).



**Fig. 3.17** Twisting and turning down at same time to maintain compression

Because of the difficulty of manipulating the fragments and the positioning of the fragments, passage of the wires can be difficult. A trick is to first pass the wire through the constant, stable fragment, and then rotate the less stable

fragment to gain access to the hole in order to pass the wire. An 18- or 21-gauge needle can be helpful to find the under-surface hole (Figs. 3.18, 3.19, 3.20, and 3.21).



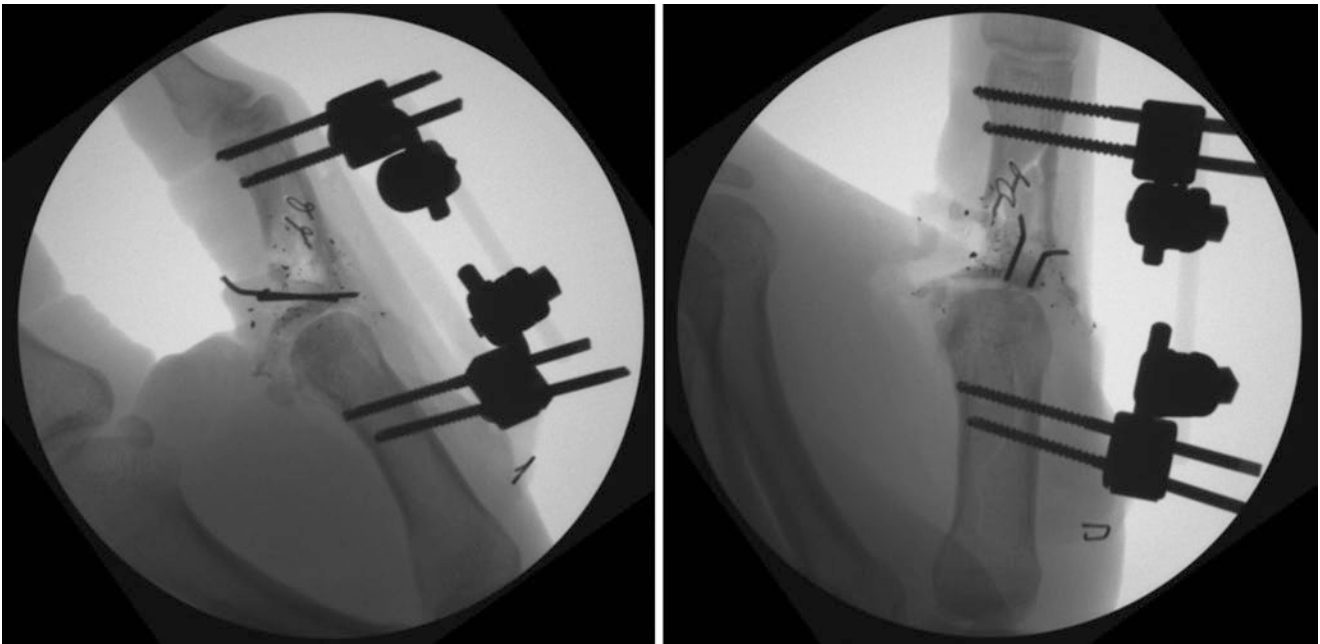
**Fig. 3.18** Interosseous wire insertion through a stable, constant fragment; then the mobile fragment is rotated and the wire is placed through the hole on the endosteal side, and then reduced and tightened



**Fig. 3.19** Injury radiographs



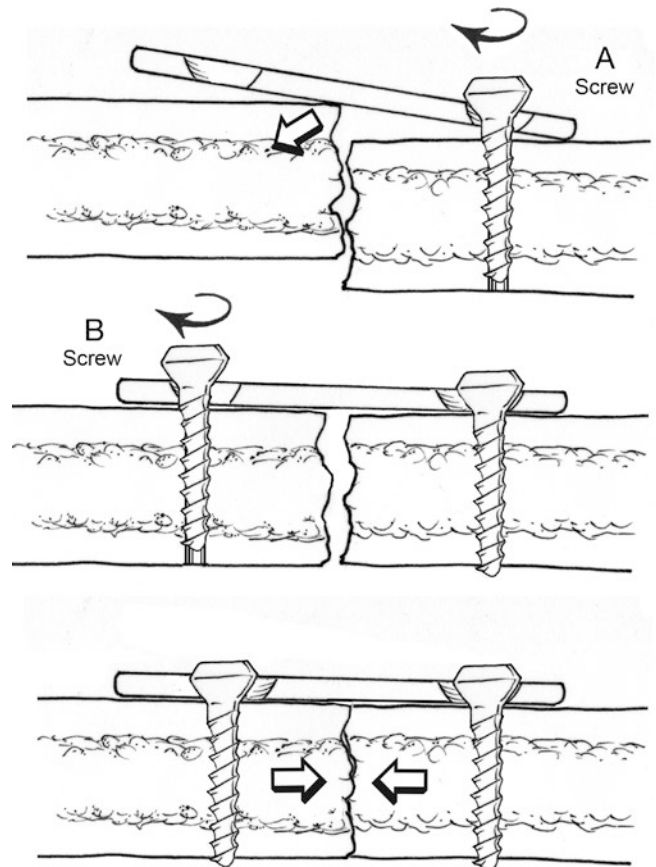
**Fig. 3.20** Clinical example of wire passage through fragments during fixation of thumb proximal phalanx fracture



**Fig. 3.21** Intraoperative fixation radiographs

### 3.1.9 Using the Plate for Reduction

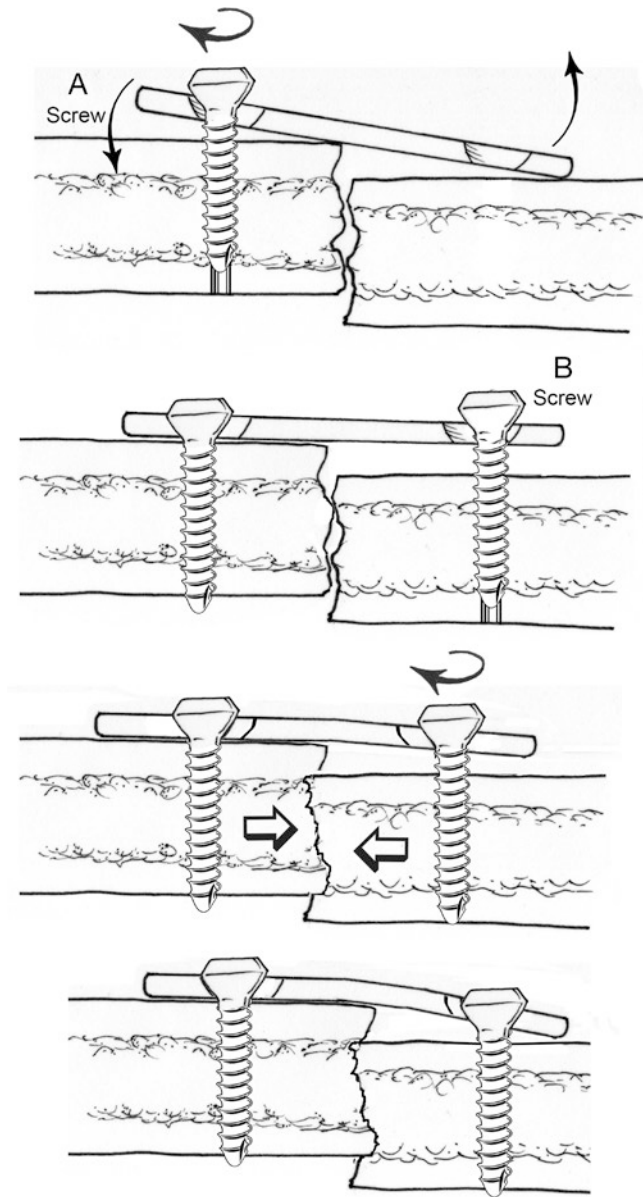
Another technique used, not necessarily just for mini-fragment reduction, is to use the plate for reduction if one is dealing with a step-off. When dealing with a diaphyseal step-off, the plate fixation should begin on the depressed side, not the high side. By placing the plate on the depressed side and tightening the screw, the distal fragment or high fragment will be pushed slightly away from the lower fragment, so as to disengage and still allow the plate to realign the cortex. The compression screw can then be placed in the opposite fragment (Fig. 3.22).



**Fig. 3.22** Plate used to assist in reduction, then compression



If one first puts a screw in the high side and then attempts to compress in the low side, the compression will block and lock the fragment from making the translation to the under-surface of the plate (Fig. 3.23).

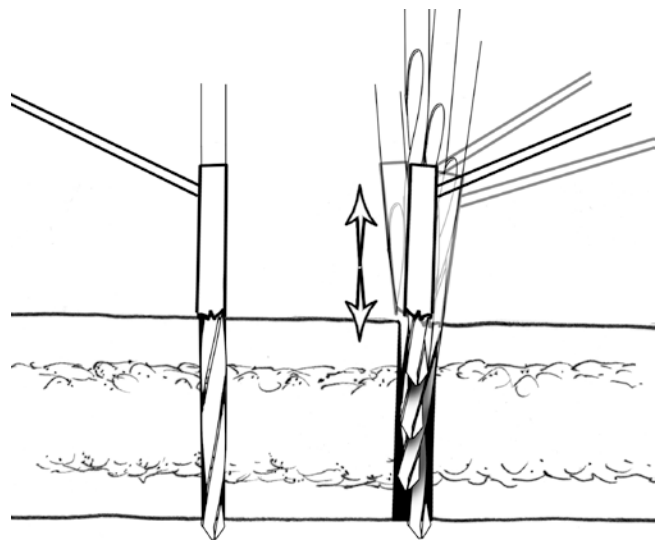


**Fig. 3.23** Fracture malalignment when using wrong screw sequence

### 3.1.10 Concerns with “Tapping” When Drilling Bone

There is one technique in reference to drilling that I find nearly reprehensible. I am unsure of its etiology, but I have encountered its use by a vast number of residents and fellows, who perform a tapping or sounding technique as they drill through a bone. I find this an extraordinarily poor technique for several reasons:

- **Hole enlargement.** If you are trying to enlarge a hole and have only one drill bit, you can merely take the drill in and out a number of times; this will cut the side walls, thereby increasing the size of the hole. The technique of tapping does not make it possible to go straight in and out without variance or wobble. With tapping, you risk losing your ultimate screw bone purchase (Fig. 3.24).

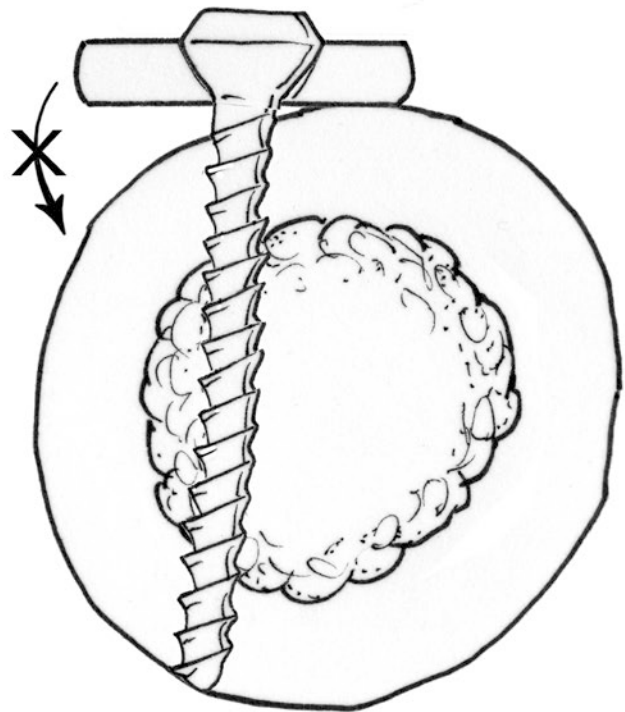
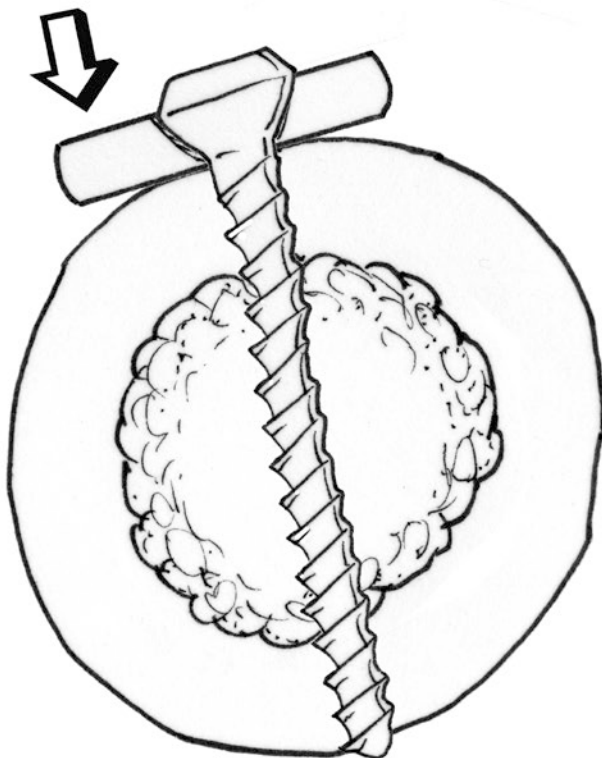
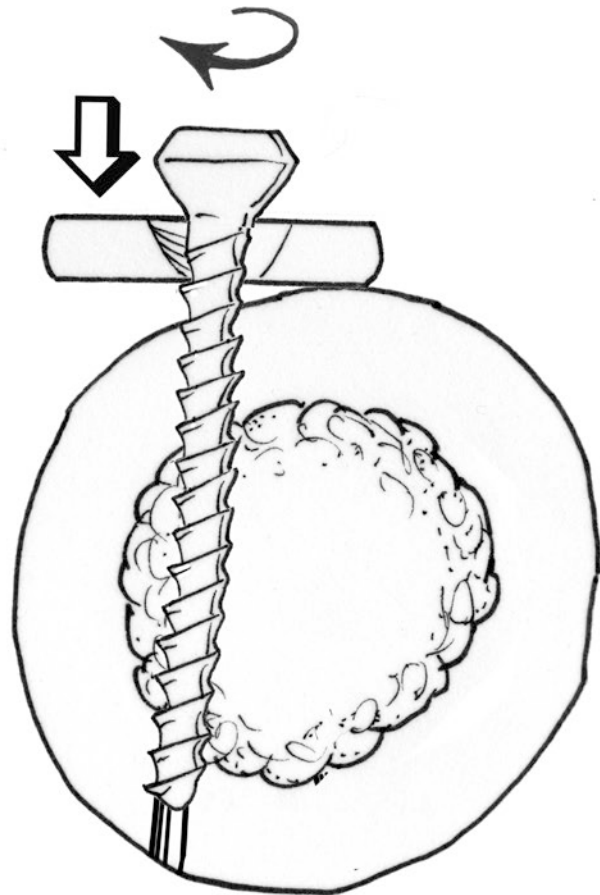
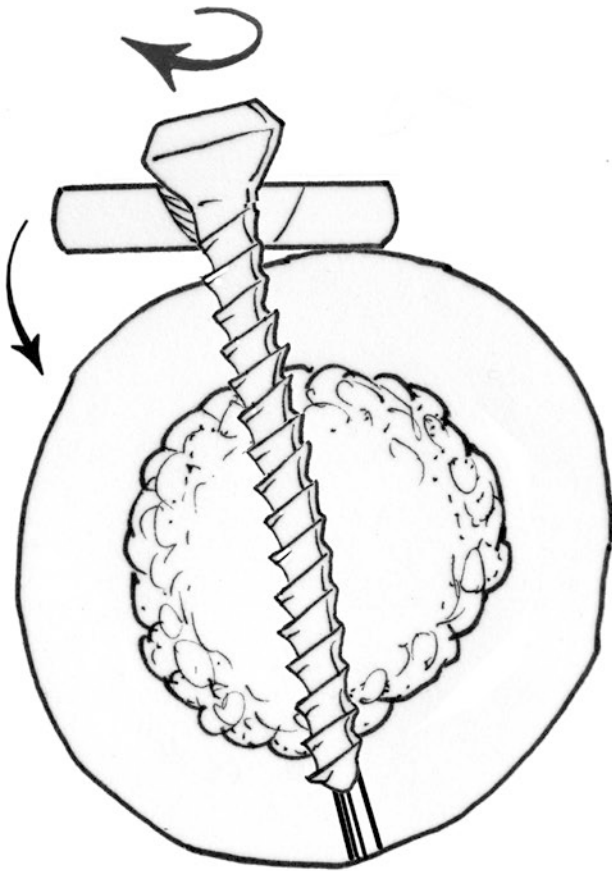


**Fig. 3.24** Hole enlarged when tapping with drill bit

- **Loss of proprioception.** I have seen a number of cases in which residents plunged through the bone they drilled because they were tapping and didn't have the proprioceptive feedback.
- **Concern for depth acquisition.** Before approaching any bone, you should know within approximately 2–4 mm what the ultimate screw length will be. For example, in men the radial shaft is about 16–18 mm and the humerus is 24–28 mm. The drilling is the second check. And finally, the depth gauge should be used for confirmation.
- **Warning against crossing principles.** I have seen residents trying to use the tapping method who were moving the drill back and forth without reversing it, not realizing that they were crossing principles; they didn't remember that they were using a drill, as opposed to a tap, as they went through the bone.

Therefore, I feel that the tapping method should be summarily discouraged, except in certain situations in the pelvis, where I'm told it is helpful.

I also would like to admonish individuals to pay attention to drilling perpendicular to the bone and not perpendicular to the plate (Figs. 3.25 and 3.26).



**Fig. 3.25** Plate seated on bone when hole has been drilled perpendicular to the bone

**Fig. 3.26** Failure to seat plate if pilot hole is drilled perpendicular to the plate

### 3.1.11 Cortical vs. Lateral Screws and Screw Seating

The plate will pull down to the bone if you are trying to attain bicortical purchase with well-seating of the head of the screw and the plate. One needs to drill perpendicular and not on an angle, unless that is indicated. Biomechanical studies have demonstrated some screw obliquity, with some increase of strength in various constructs [17].

Finally, in plate selection, I feel that very rarely is a locked plate required in a diaphyseal construct. Therefore, if I'm using a plate with locking and non-locking options, I primarily use cortical screws. If I do have a scenario with a metaphyseal component in my fixation, I generally apply a cortical screw, followed by a locking screw at the most distal aspect of the locking plate, and then use cortical screws for the remainder. The distal radius is one example.

One study by Bottlang *et al.* [18] looked at cortical screws *versus* locking screws and the resulting stress concentration, particularly at the ends of plates with locking screws. They found that the locking screws reduced the axial stiffness of the locked plate.

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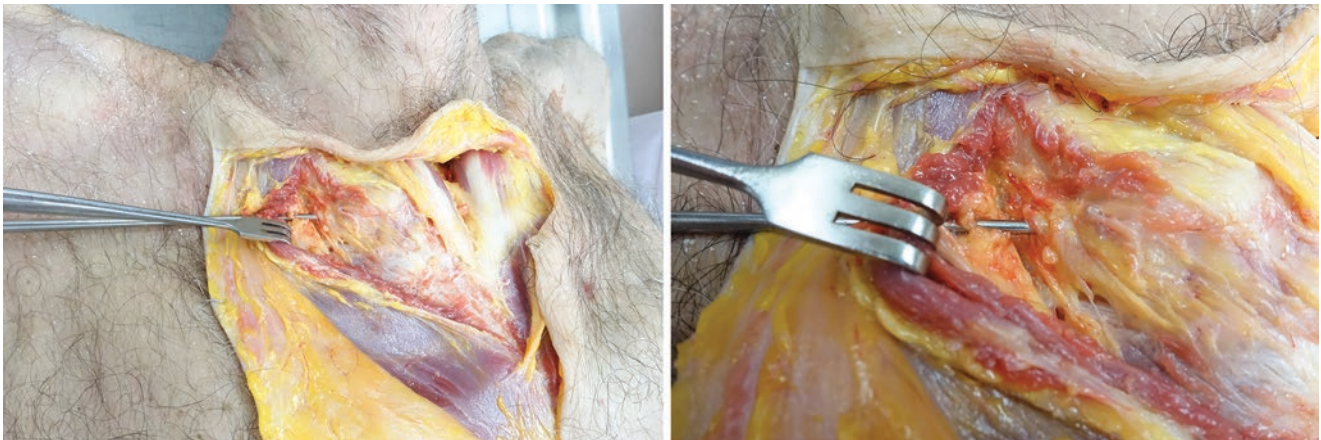


### 4.1 Diagnosis and Treatment Choice

The rarity of sternoclavicular joint dislocations make the development of a treatment algorithm or protocol difficult, even when assimilating both personal experience and reports in the literature, which consist of small numbers of patients. There is also controversy concerning the primary stabilizer of the sternoclavicular joint, as authors express differing

opinions on the primary stabilizer. Groh and Wirth [1] list these stabilizers:

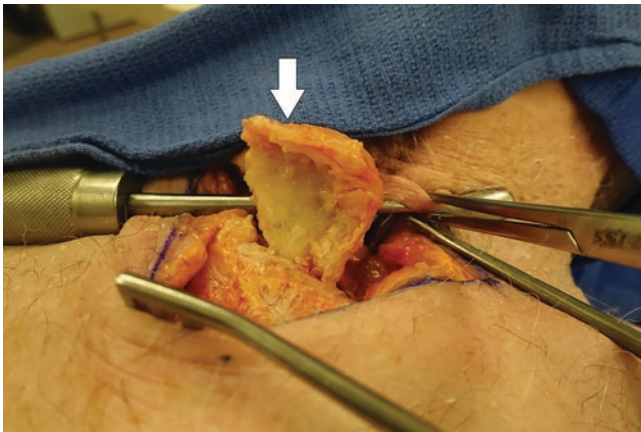
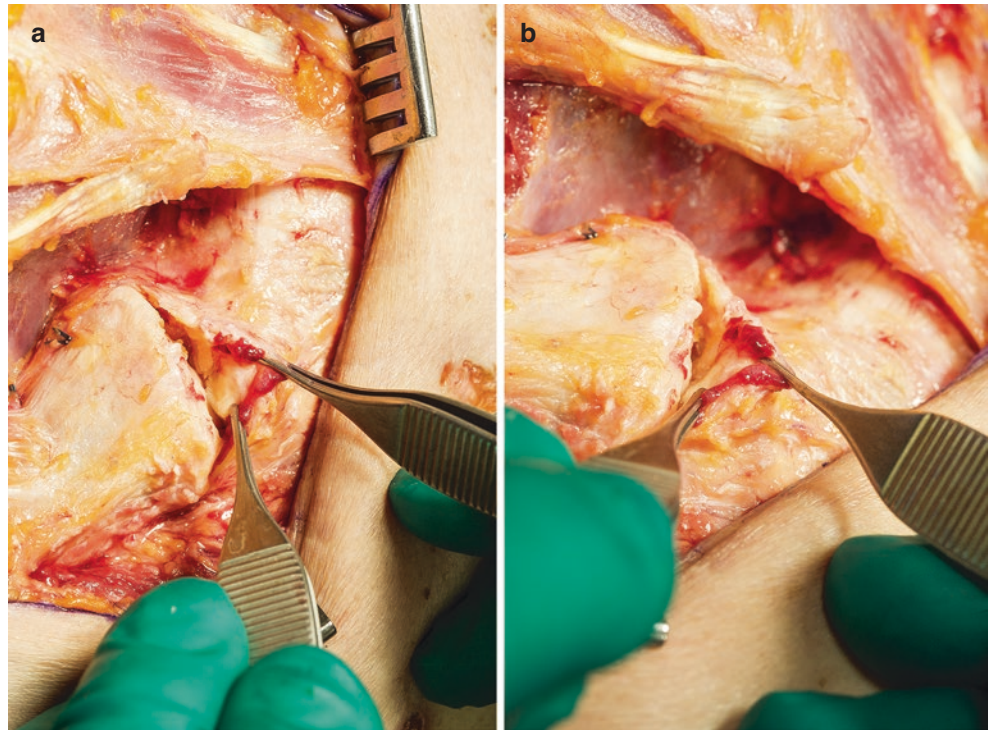
1. Costoclavicular (rhomboid) ligament (Fig. 4.1)
2. Intraarticular disk (Fig. 4.2)
3. Anterior capsule (Fig. 4.3)
4. Interclavicular ligament (Fig. 4.4)



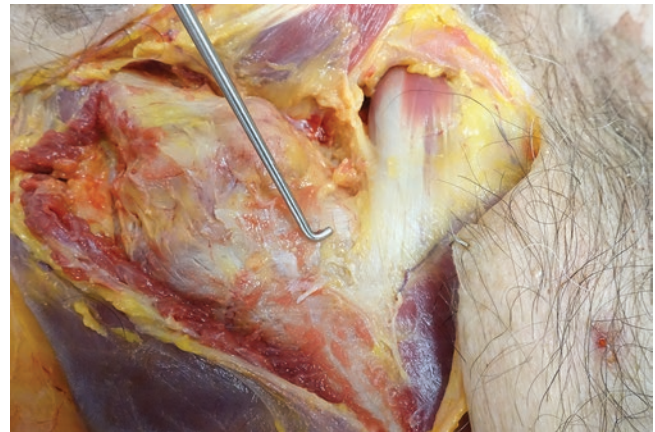
**Fig. 4.1** Right-side costoclavicular ligament, with probe under ligament



**Fig. 4.2** Right-side intraarticular disk, in picks to the left



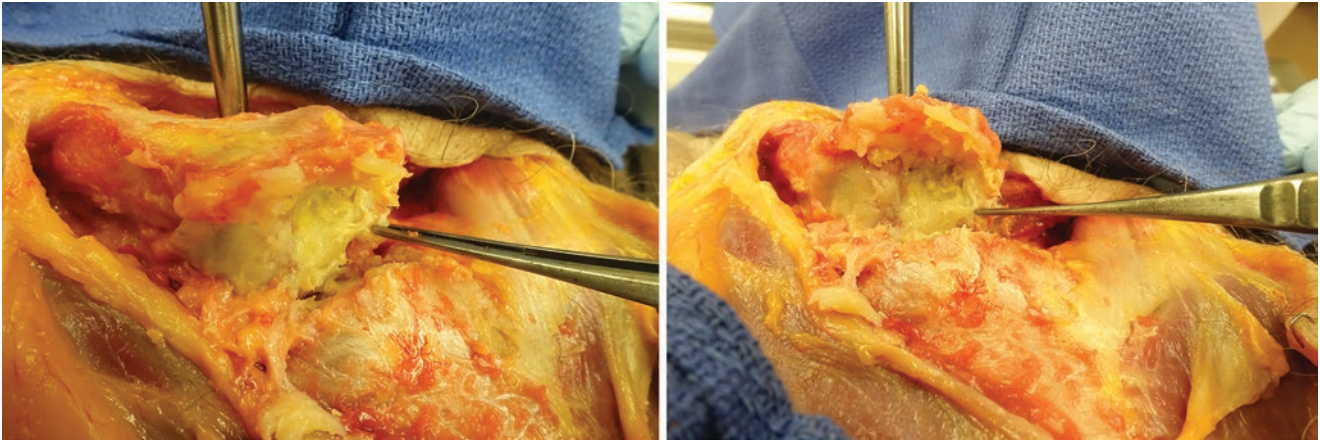
**Fig. 4.3** Right-side clavicle viewed from left side to anterior capsule (arrow)



**Fig. 4.4** Interclavicular ligament

Spencer et al. [2] list these:

1. Posterior sternoclavicular joint capsule (Fig. 4.5)
2. Anterior capsule
3. Costoclavicular ligament
4. Interclavicular ligaments



**Fig. 4.5** Pickup holding posterior ligament in arthritic sternoclavicular (SC) joint

Sternoclavicular joint dislocations, whether anterior or posterior, are tempting candidates for closed reduction. However, anterior dislocation reductions are usually unsuccessful in maintaining reduction, as noted by Groh and Wirth [1] and de Jong and Sukul [3], who reported successful outcomes in 13 patients with anterior dislocations treated without attempts at reduction.

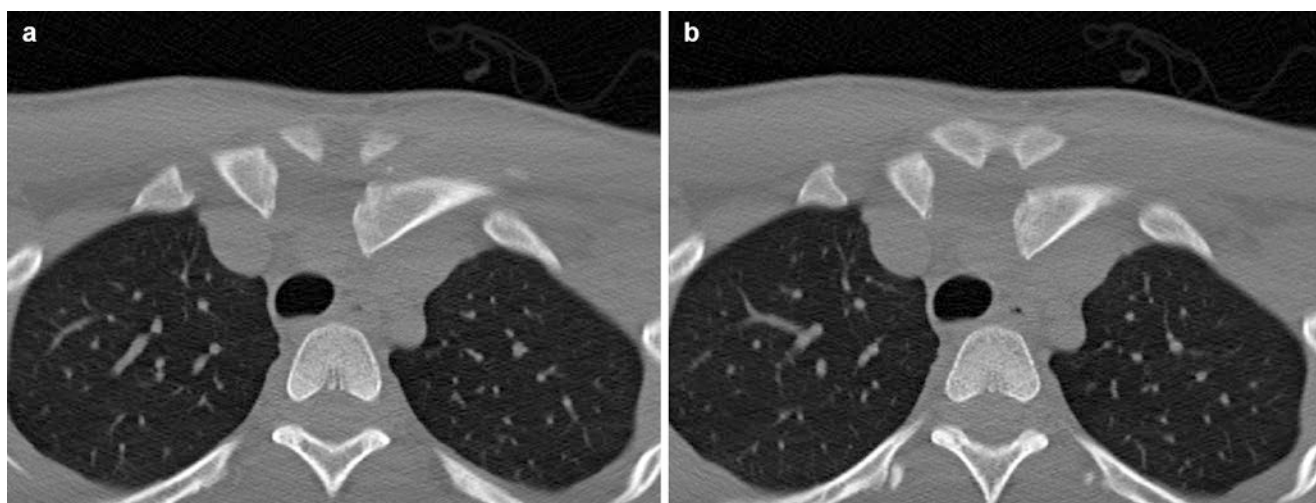
Posterior dislocations, according to Groh et al. [4], demonstrate about a 38% success rate of reduction maintenance if performed within 10 days. A recent meta-analysis by Tepolt et al. [5] in adolescent patients with posterior dislocations demonstrates about a 50% success rate if the reduction is performed within 48 hours. Difficulty in successfully treating the adolescent medial clavicle injury arises because most medial injuries are physeal injuries, not dislocations [5]. Initial diagnosis is difficult, as is confirming successful reduction in either dislocations or physeal injuries. Clinical complications and ramifications are similar for dislocations and physeal injuries because of the anatomic relationship to the mediastinum. Therefore, the treatment algorithm is similar for either. As noted by Waters et al. [6], it is important to confirm that reduction has in fact occurred. Even with the use of the serendipity view, confirmation of a successful reduction can be difficult.

This brings into question the diagnosis and studies of choice for the evaluation of the initial injury or subsequent reductions. I have found serendipity views to be very difficult to evaluate, even in the operating room under ideal positioning conditions. Optimally, a CT scan is obtained to confirm the diagnosis. I have found the 3D CT scan particularly helpful for this injury (Figs. 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, and 4.12).

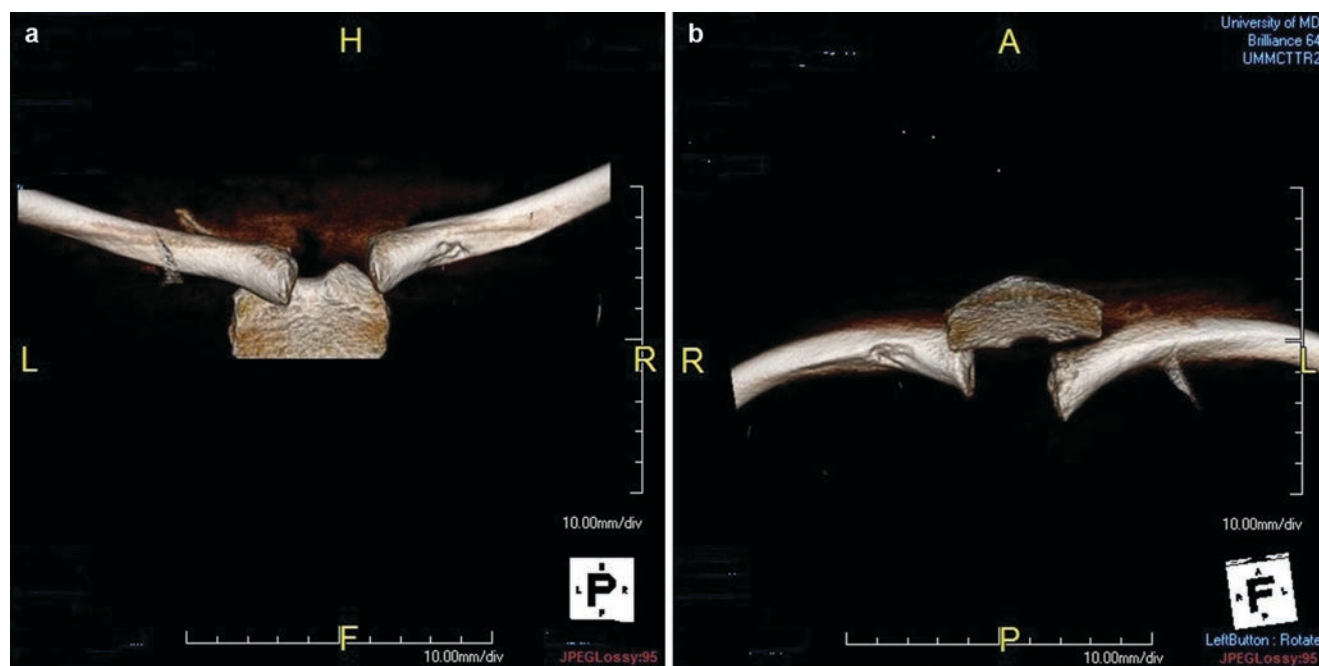


**Fig. 4.6** Left clavicle radiograph with difficulty in discerning pathology at left SC joint

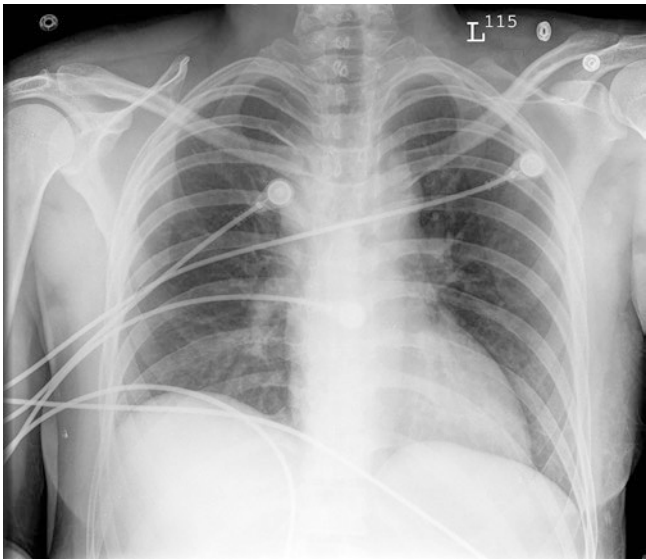




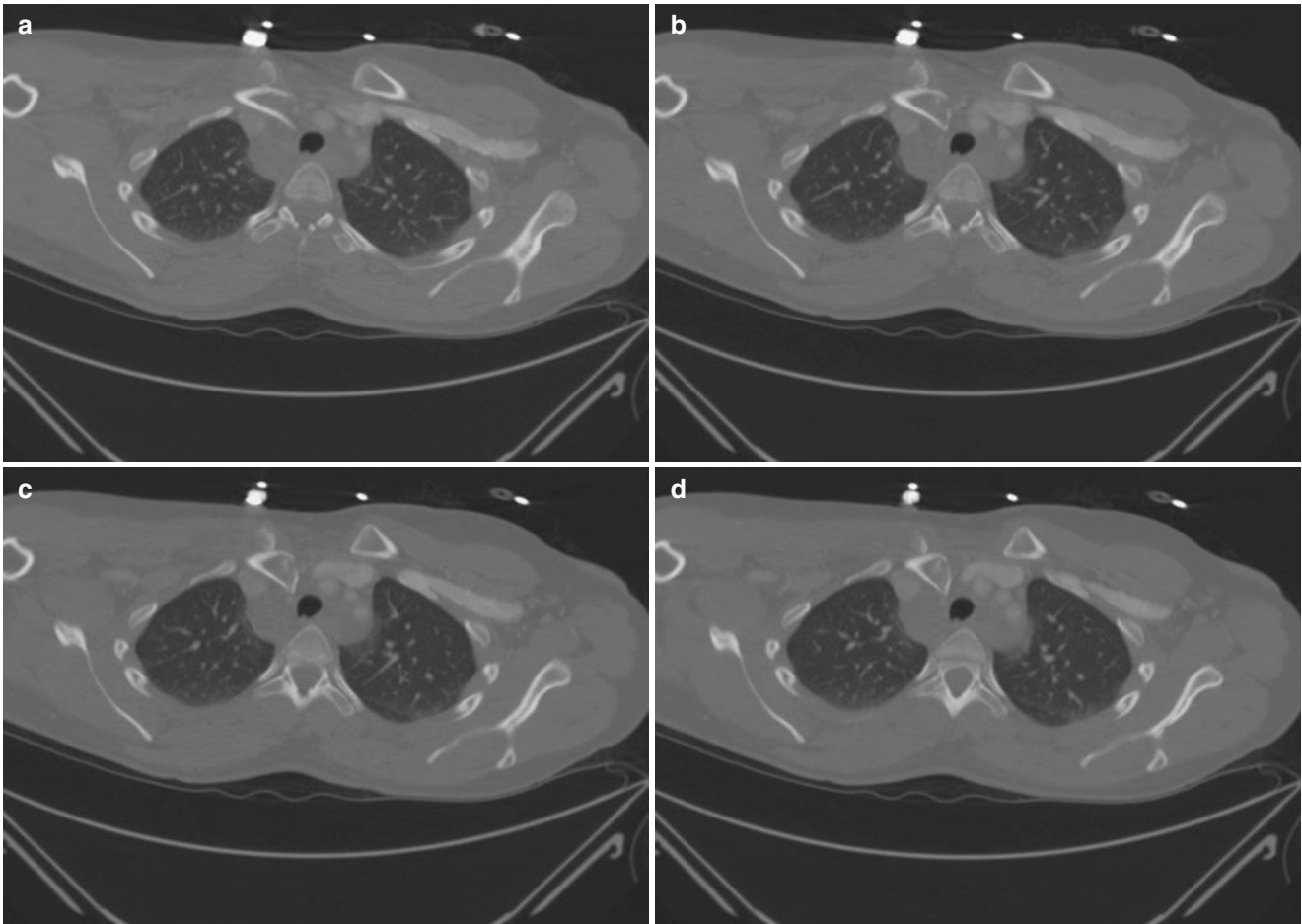
**Fig. 4.7** CT scan demonstrating posterior dislocation of left SC joint



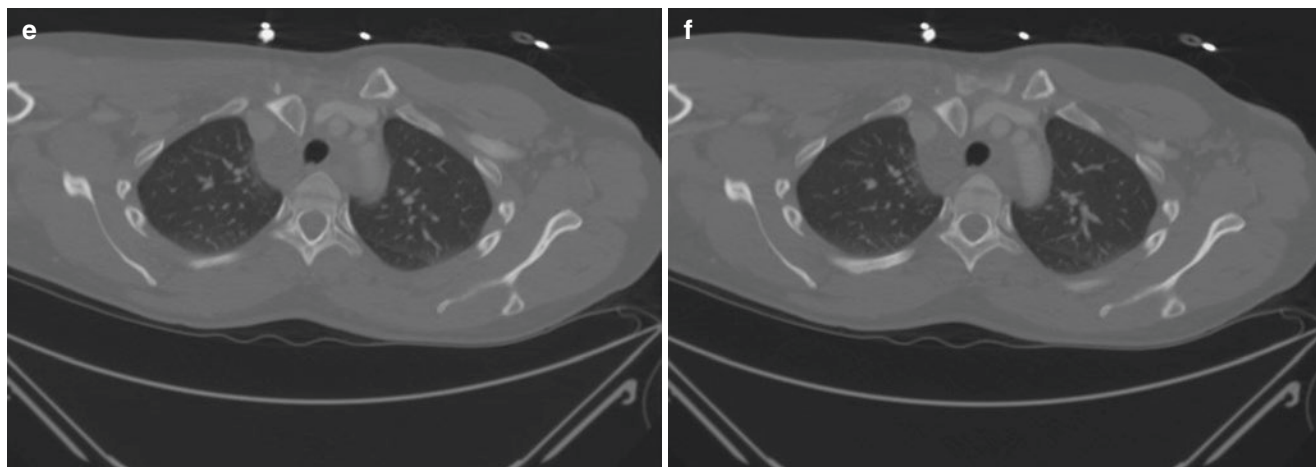
**Fig. 4.8** 3D CT scan showing left-sided posterior SC dislocation



**Fig.4.9** Chest X-ray with right SC joint fracture dislocation



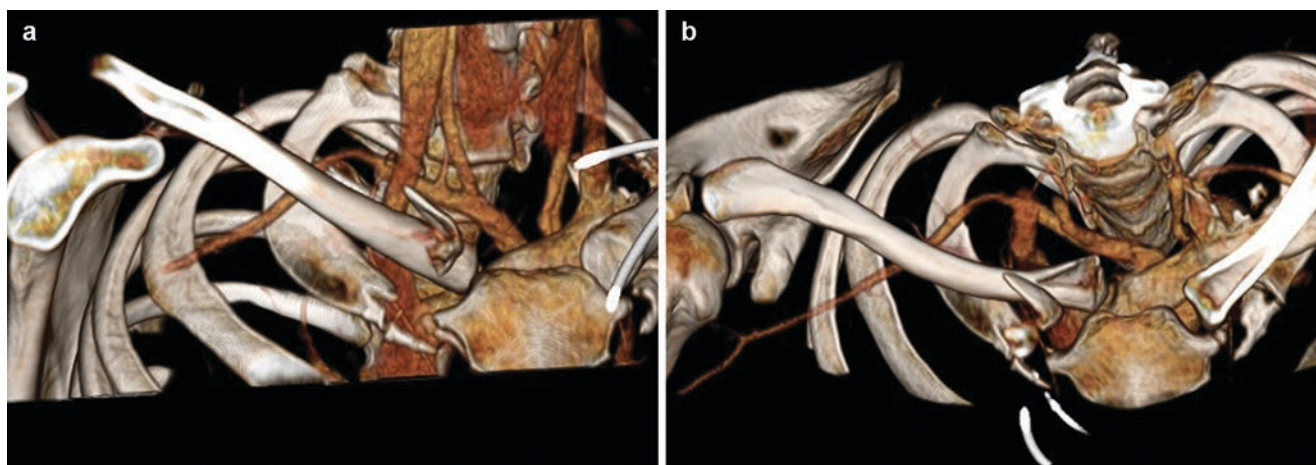
**Fig.4.10** (a–f) CT scans with right posterior SC joint fracture dislocation



**Fig. 4.10** (continued)



**Fig. 4.11** Soft-tissue CT scan demonstrating brachiocephalic vein indentation



**Fig. 4.12** CT scan of right-sided posterior SC dislocation



After a closed reduction maneuver is attempted in the OR, a CT scan is needed. The patient must leave the OR to obtain the scan and then undergo a second anesthetic if the reduction was not successful.

After making a diagnosis of sternoclavicular joint dislocation, I counsel the patient about treatment, considering the probability that closed reductions generally don't work. Anterior dislocations are treated in a closed fashion, generally without any attempt at closed reduction. Open reduction internal fixation (ORIF) with ligament repair is performed in acute posterior dislocations, with possible ligamentous reconstruction. Delayed posterior dislocations, painful or not, should undergo open reduction and ligamentous reconstruction. Catastrophic complications have been reported in patients with untreated posterior dislocations [7–9].

The experience at Shock Trauma since 2006 has demonstrated sternoclavicular joint injuries in 37 patients. The distribution can be seen in Table 4.1.

**Table 4.1** Sternoclavicular joint dislocation injuries: treatment summary of 37 patients

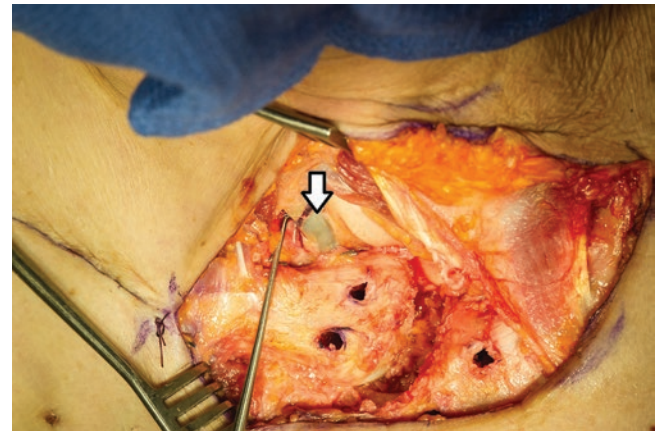
Injury	Patients (n)	Treatment
SH-I Physeal fracture, left posterior	5	Acute Rx #5 Ethibond Excel®
SH-IV Physeal fracture, left posterior	1	Acute Rx #5 Ethibond Excel®
Anterior acute dislocation	3 right; 4 left	Closed treatment, no reduction attempt
Posterior acute dislocation	7	Open reduction; right ligament repair (1 after failed attempt at closed reduction)
	5	Open reduction; left ligament repair (1 after failed attempt at closed reduction)
	1	Open reduction; left ligament reconstruction
Anterior fracture dislocation—acute	1	Right ORIF
Posterior fracture dislocation—acute	1	Right ORIF
Posterior dislocation—acute on chronic after prior ligament reconstruction	1	Right ligament reconstruction
Anterior chronic dislocation	1	Left ligament reconstruction
Posterior chronic dislocation	1	Right ligament reconstruction
	1	Left ligament reconstruction
Multidirectional chronic dislocation	3	Left ligament reconstruction
	1	Right ligament reconstruction
	1	Left sternoclavicular fusion

ORIF open reduction and internal fixation, SH Salter–Harris classification

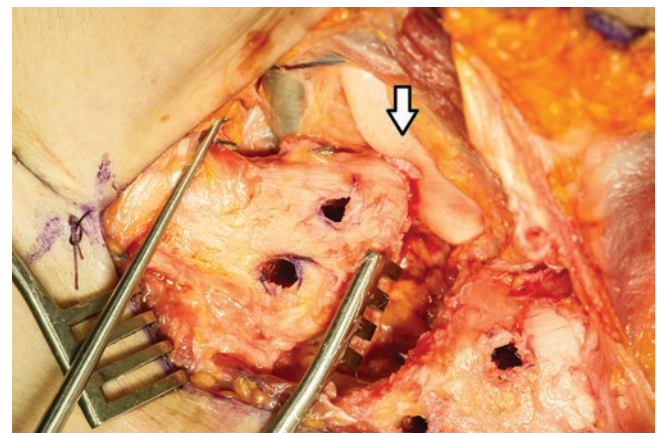
## 4.2 Operative Techniques

### 4.2.1 Setup and Incision

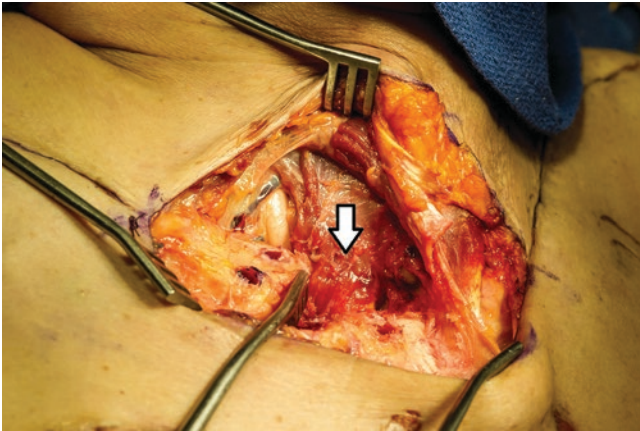
The approach for either acute or chronic dislocation uses similar setup and incision. I do make the cardiothoracic surgeon aware of the procedure to be performed, but I prefer to perform my own approaches and tend not to have the cardiothoracic surgeon perform this intervention. The close relationship of the sternoclavicular joint to mediastinal structures needs to be appreciated. As noted by Ponce et al. [10], the closest is the brachiocephalic vein, 6.6 mm from the sternoclavicular joint, followed by the common carotid (Figs. 4.13, 4.14, 4.15, and 4.16).



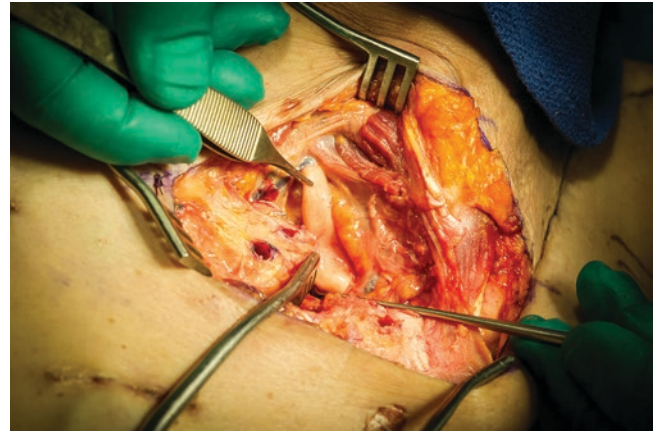
**Fig. 4.13** Right internal jugular junction to brachiocephalic vein (arrow)



**Fig. 4.14** Common carotid artery (arrow)



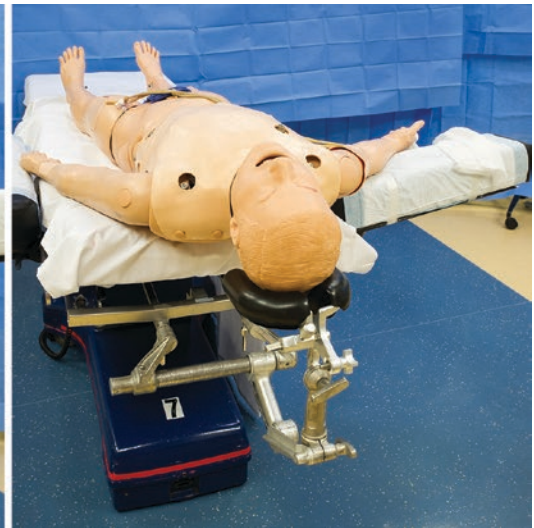
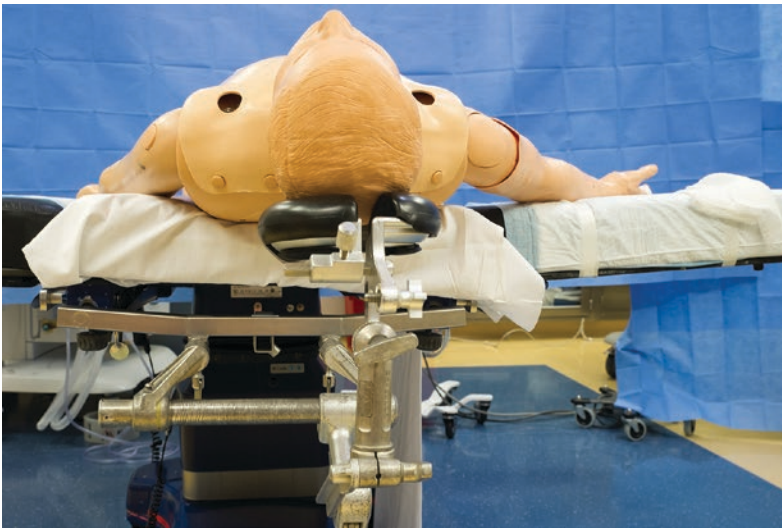
**Fig. 4.15** Sternothroid (*arrow*)



**Fig. 4.16** Right common carotid (*arrow*) in pickups

The patient is positioned supine with a bump between the scapulae. I use a Mayfield headrest to let the neck extend, and I prep the entire thorax and abdomen, as well as the arm

located to the side of the sternoclavicular joint dislocation (Figs. 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23, 4.24, 4.25, 4.26, 4.27, 4.28, 4.29, and 4.30).



**Fig. 4.17** Patient positioned on Mayfield headrest moved to right side for right SC joint dislocation, with left arm tucked at side



**Fig. 4.18** Right arm suspended



**Fig. 4.19** Two sheets folded behind operative side





**Fig. 4.20** Head secured with Kerlix® roll

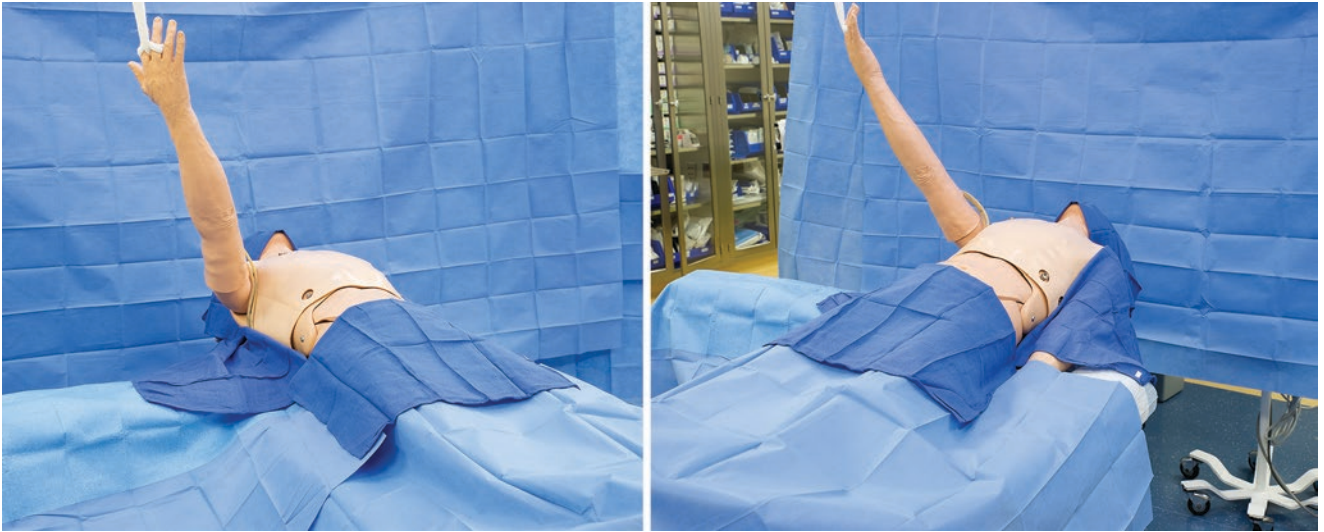


**Fig. 4.22** 3/4 reinforced sheet over arm board

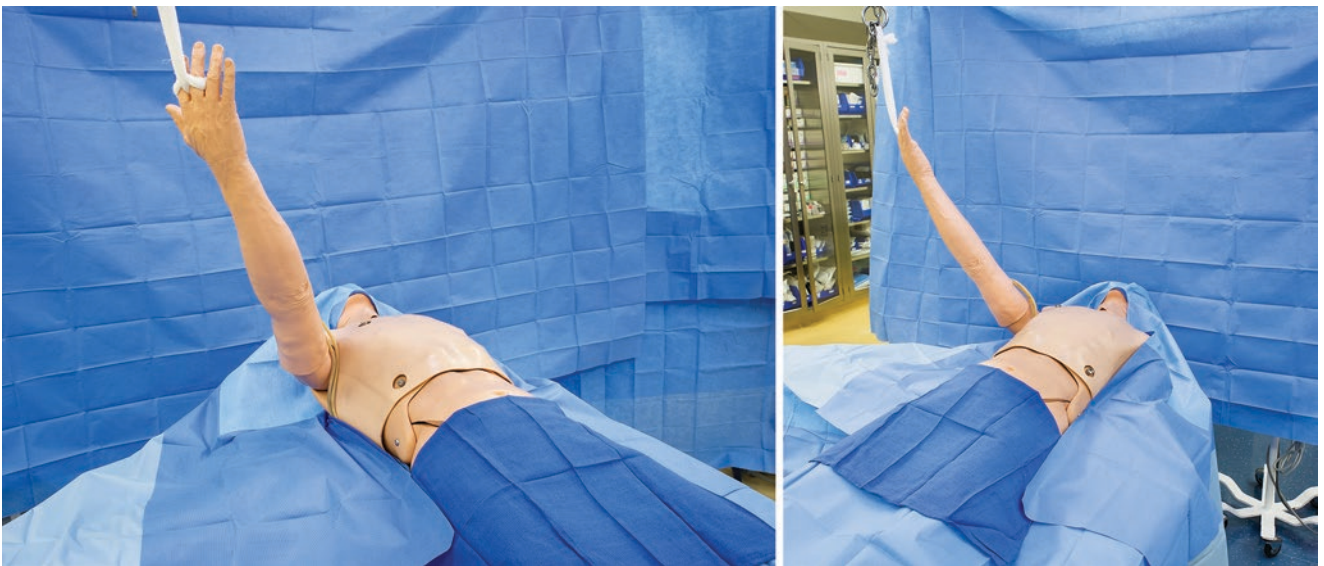


**Fig. 4.21** Body drape to level of umbilicus





**Fig. 4.23** Towels around operative field

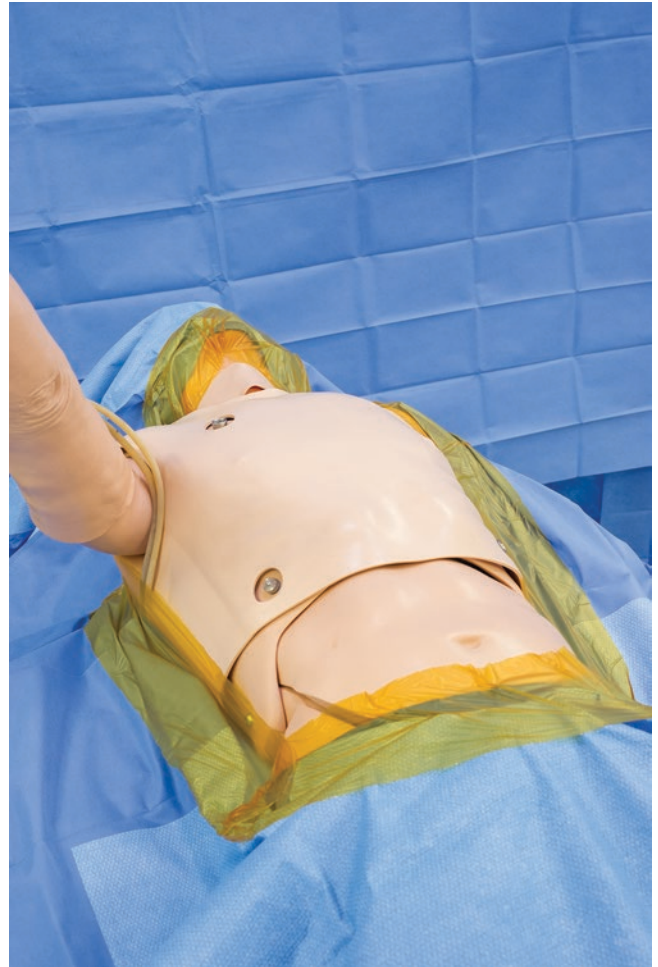


**Fig. 4.24** Split drape tails down





**Fig. 4.25** Split drape tails up



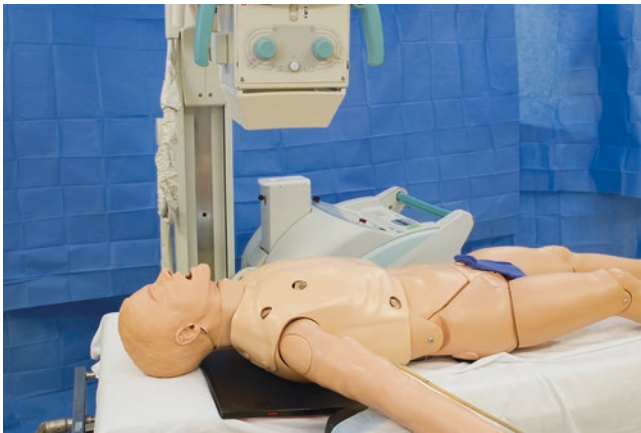
**Fig. 4.26** Ioban™ strips around perimeter



**Fig. 4.27** Hand down from suspension



**Fig. 4.28** Fingers painted

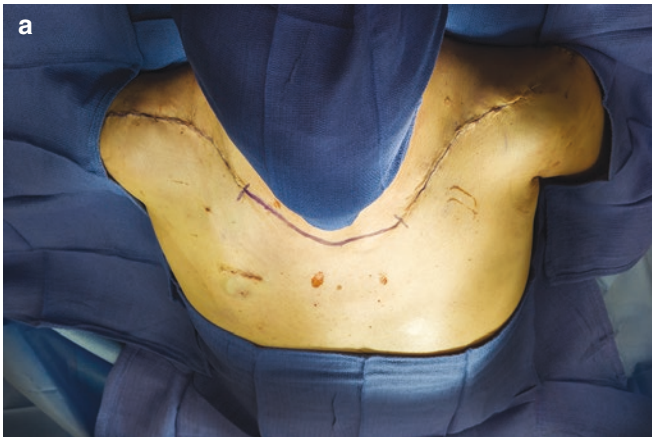


**Fig. 4.29** Intraoperative radiograph, AP view



**Fig. 4.30** Intraoperative radiograph, lordotic

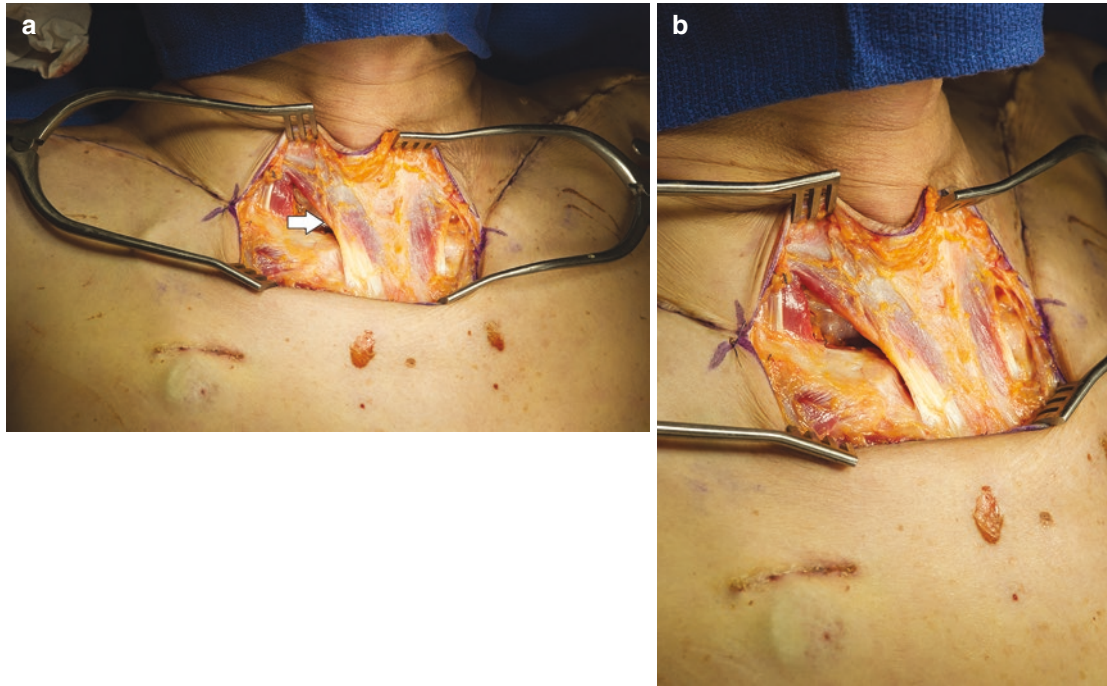
The incision is distal on the superior aspect of the clavicle and curving in the manubrial notch, continuing slightly to the opposite side to allow access to the opposite clavicle (Fig. 4.31).



**Fig. 4.31** (a, b) Incision for approach to right SC joint (marked in *purple*)



The skin incision is performed and, if possible, the supraclavicular nerves are preserved. The sternocleidomastoid requires reflection to expose the sternoclavicular joint (Figs. 4.32 and 4.33).

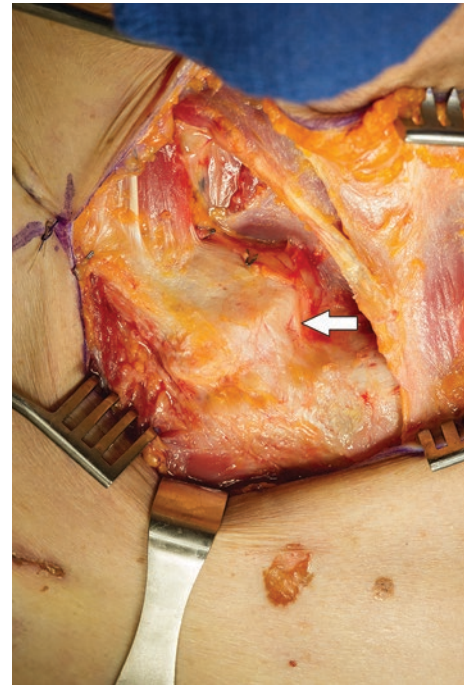


**Fig. 4.32** (a and b) Sternocleidomastoid (SCM), sternal head over right SC joint (*arrow*)

The anterior capsule, the costoclavicular ligaments, and the posterior ligaments need to be visualized (Fig. 4.34).



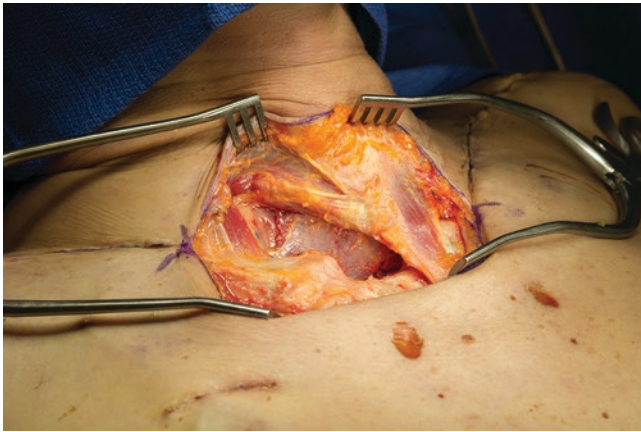
**Fig. 4.33** Reflected sternal head of SCM



**Fig. 4.34** Right SC joint and capsule, anterior capsule (*arrow*)

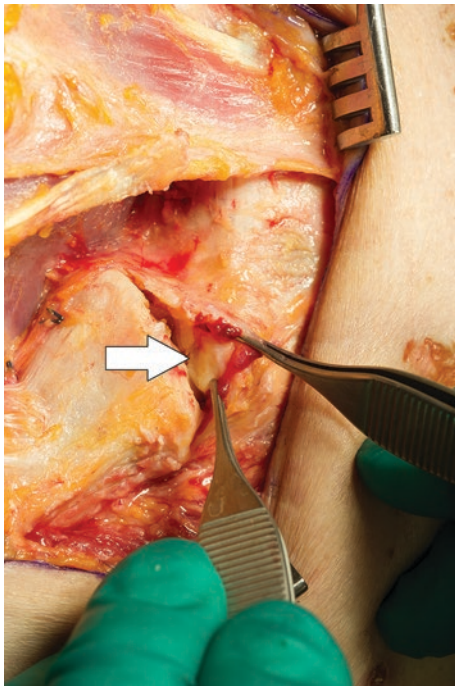


The sternohyoid and sternothyroid muscles, as demonstrated, are a protective layer between the manubrium and the mediastinal structures (Fig. 4.35).



**Fig. 4.35** Superficial sternohyoid and deeper sternothyroid muscles

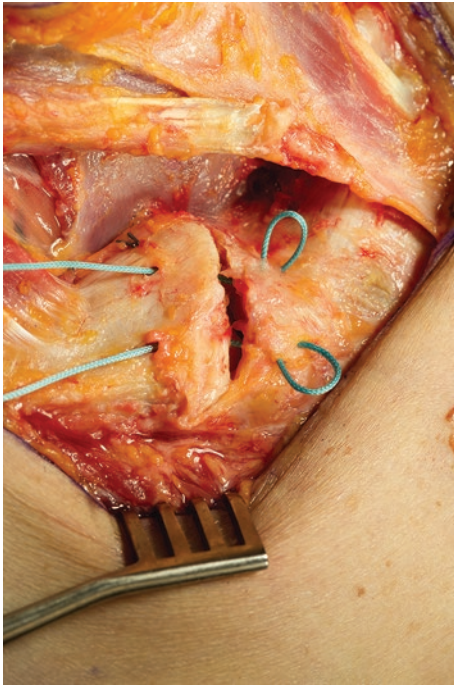
In the acute scenario, after the joint is open and if a ligamentous repair can be performed, the meniscus is preserved (Fig. 4.36).



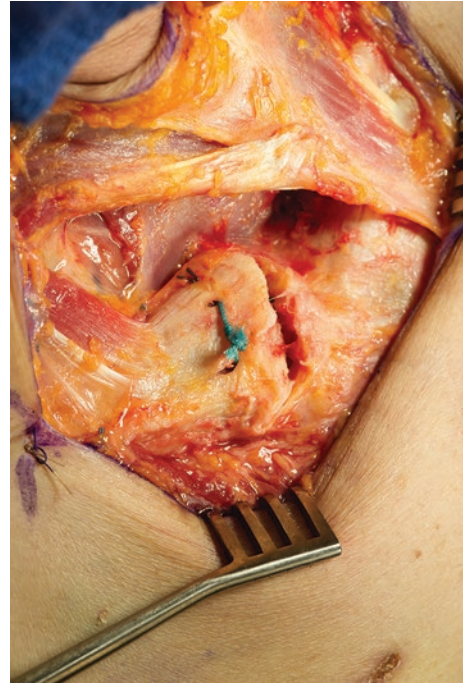
**Fig. 4.36** Articular disk, meniscus (*arrow*) in right SC joint

#### 4.2.2 Reduction of Acute Injury

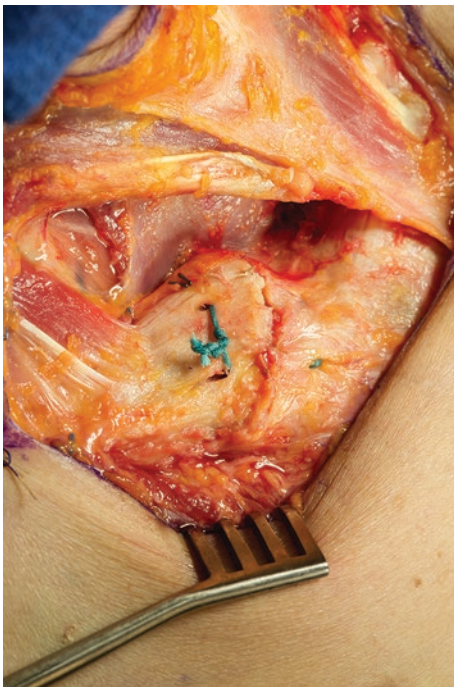
If the repair cannot be performed or if the injury is chronic, the meniscus is excised. The reduction maneuver is performed in a manner similar to that used in a closed intervention with lateral traction; the clavicle is controlled with a lion jaw or lobster claw. Do not use a towel clip, because these tend to break or bend. Visually confirm the reduction. If the dislocation is acute, and ligamentous repair can be performed, drill holes are made with a 2.5-mm drill bit. The sutures used are #5 Ethibond Excel®, which are passed through parallel holes in the clavicle or manubrium from which they were avulsed for either the anterior ligament complex (Figs. 4.37, 4.38, 4.39, 4.40, 4.41, 4.42, 4.43, 4.44, 4.45, 4.46, and 4.47), the posterior ligament complex (Figs. 4.48, 4.49, 4.50, 4.51, 4.52, 4.53, 4.54, 4.55, and 4.56), or the costoclavicular ligament complex (Figs. 4.57, 4.58, and 4.59).



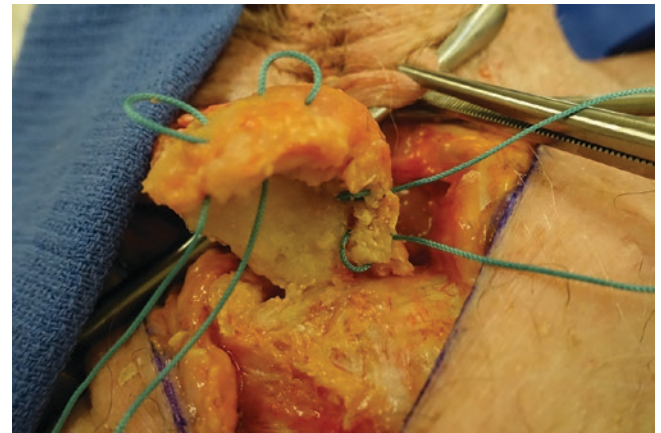
**Fig. 4.37** Acute repair of right SC joint anterior ligaments



**Fig. 4.38** Capsule with ligamentous avulsion off clavicle

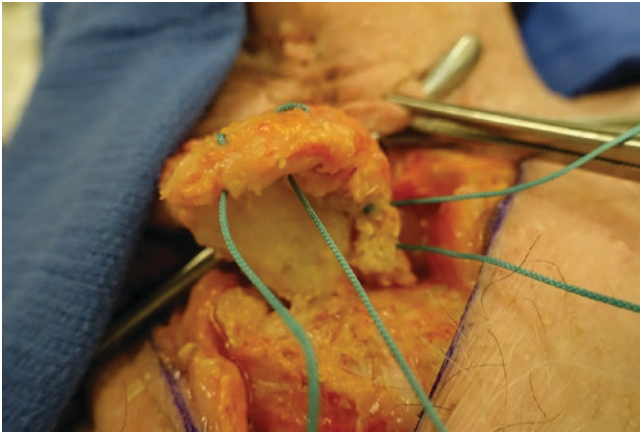


**Fig. 4.39** Sutures placed through drill holes in clavicle

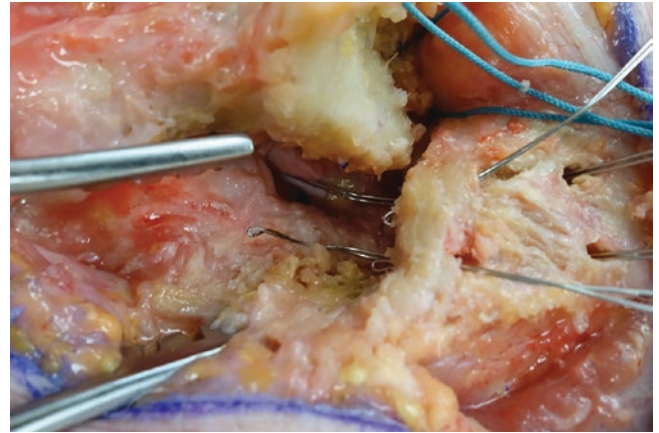


**Fig. 4.40** Different specimen with repair of anterior and posterior ligaments still attached to clavicle using #5 Ethibond Excel® locking horizontal sutures (continued in Figs. 4.41, 4.42, 4.43, 4.44, 4.45, 4.46, and 4.47)

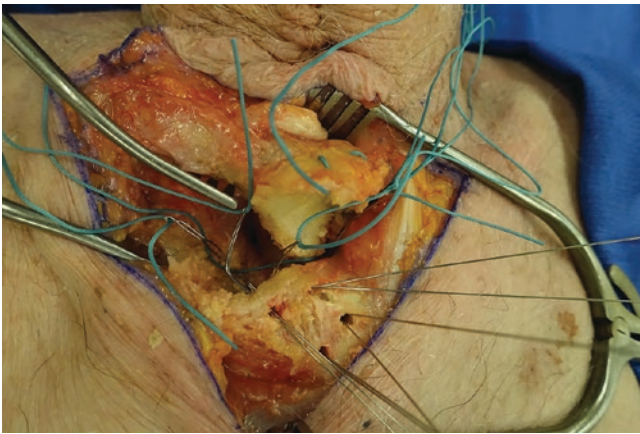




**Fig. 4.41** Sutures tensioned



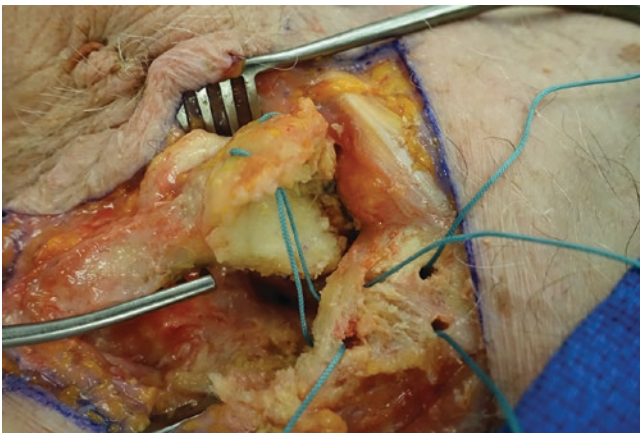
**Fig. 4.42** Drill holes thru manubrium with 24-gauge wire looped as suture passes



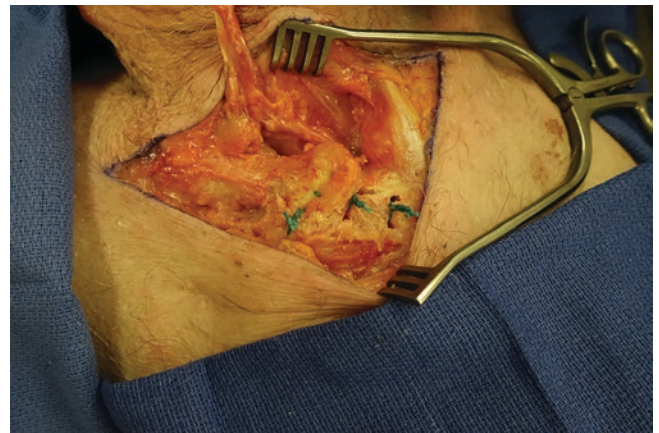
**Fig. 4.43** Sutures placed in wires



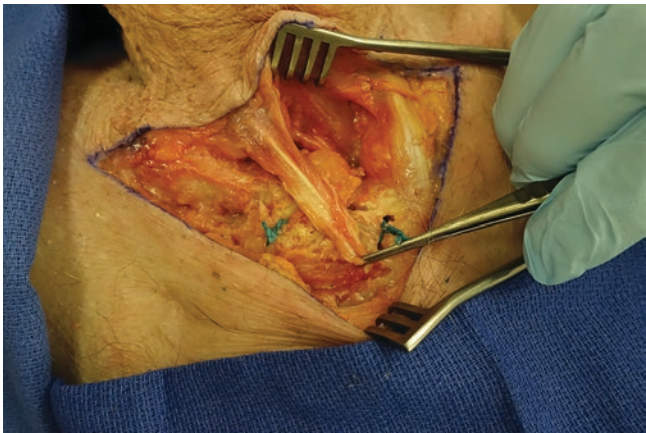
**Fig. 4.44** Correct suture placement in loop, as in upper example close to end of suture



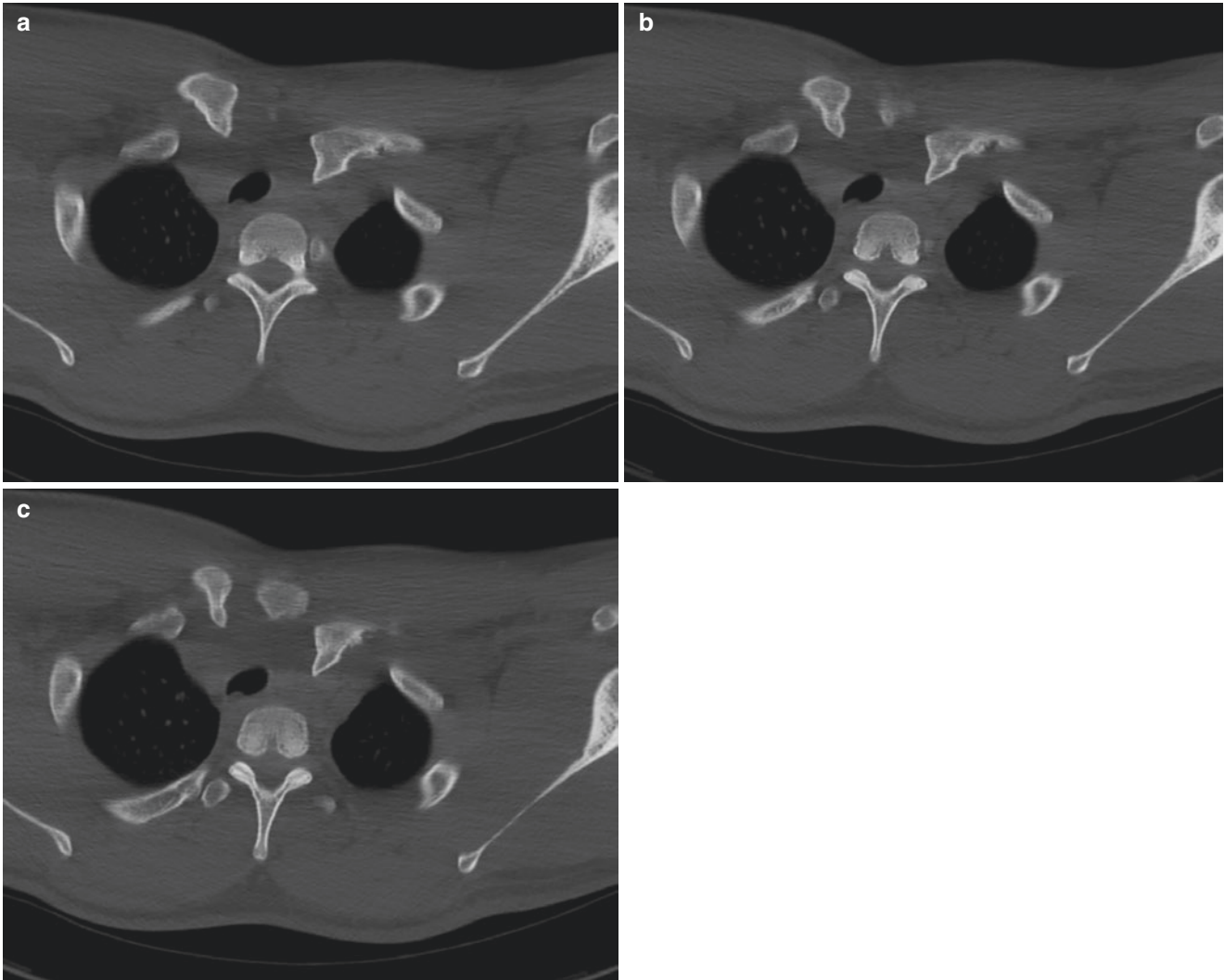
**Fig. 4.45** Sutures passed thru drill holes in manubrium



**Fig. 4.46** Sutures tied over manubrium

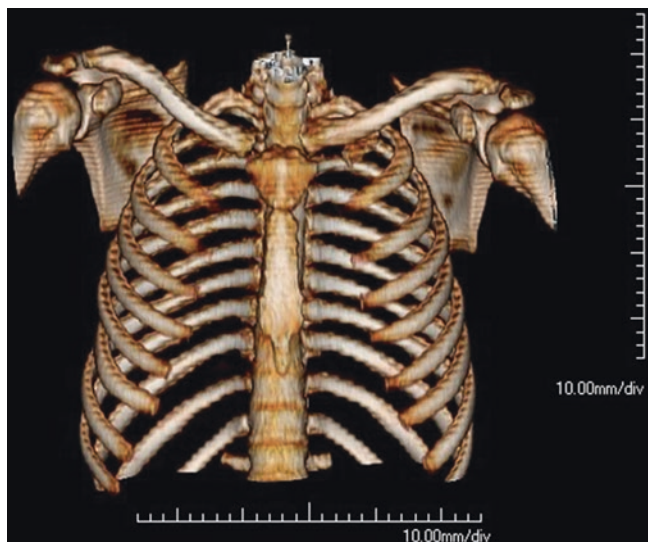


**Fig. 4.47** Sternal head of SCM repositioned



**Fig. 4.48** (a–c) CT scan and 3-D images of left SC joint posterior dislocation





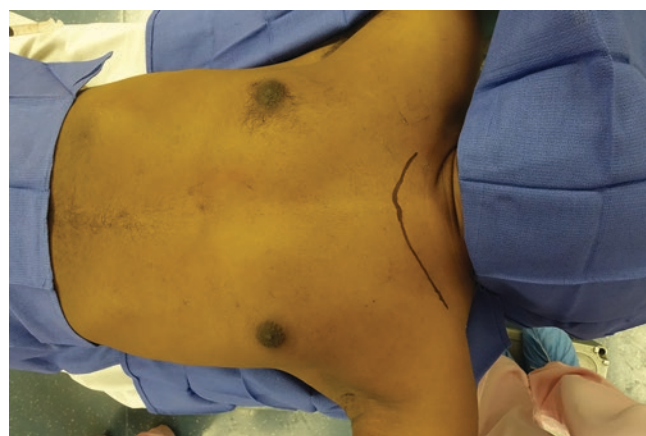
**Fig. 4.49** CT scan and 3-D images of left SC joint posterior dislocation



**Fig. 4.50** CT scan and 3-D images of left SC joint posterior dislocation



**Fig. 4.51** CT scan and 3-D images of left SC joint posterior dislocation

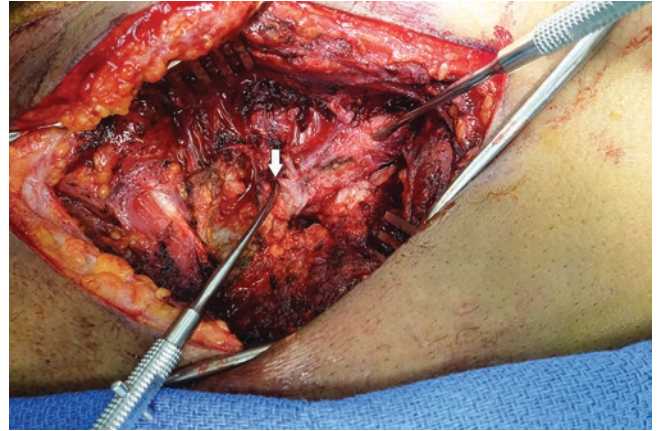


**Fig. 4.52** Clinical example of skin incision for left SC approach

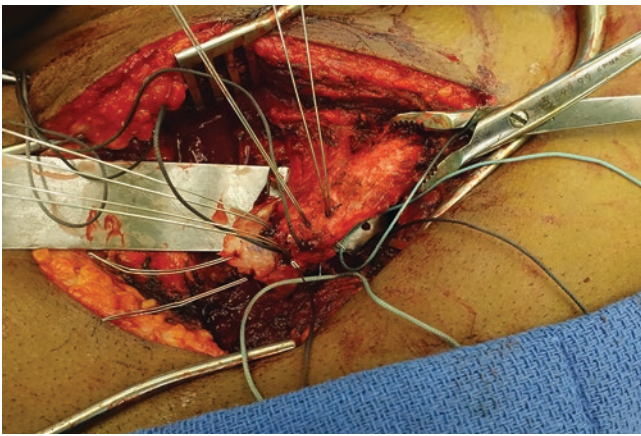




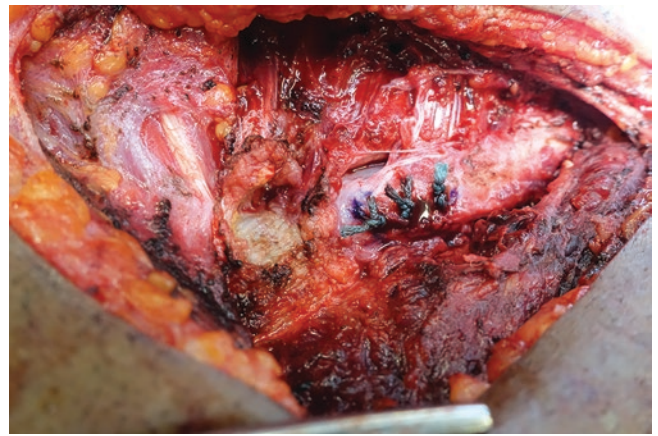
**Fig. 4.53** Dislocated left clavicle



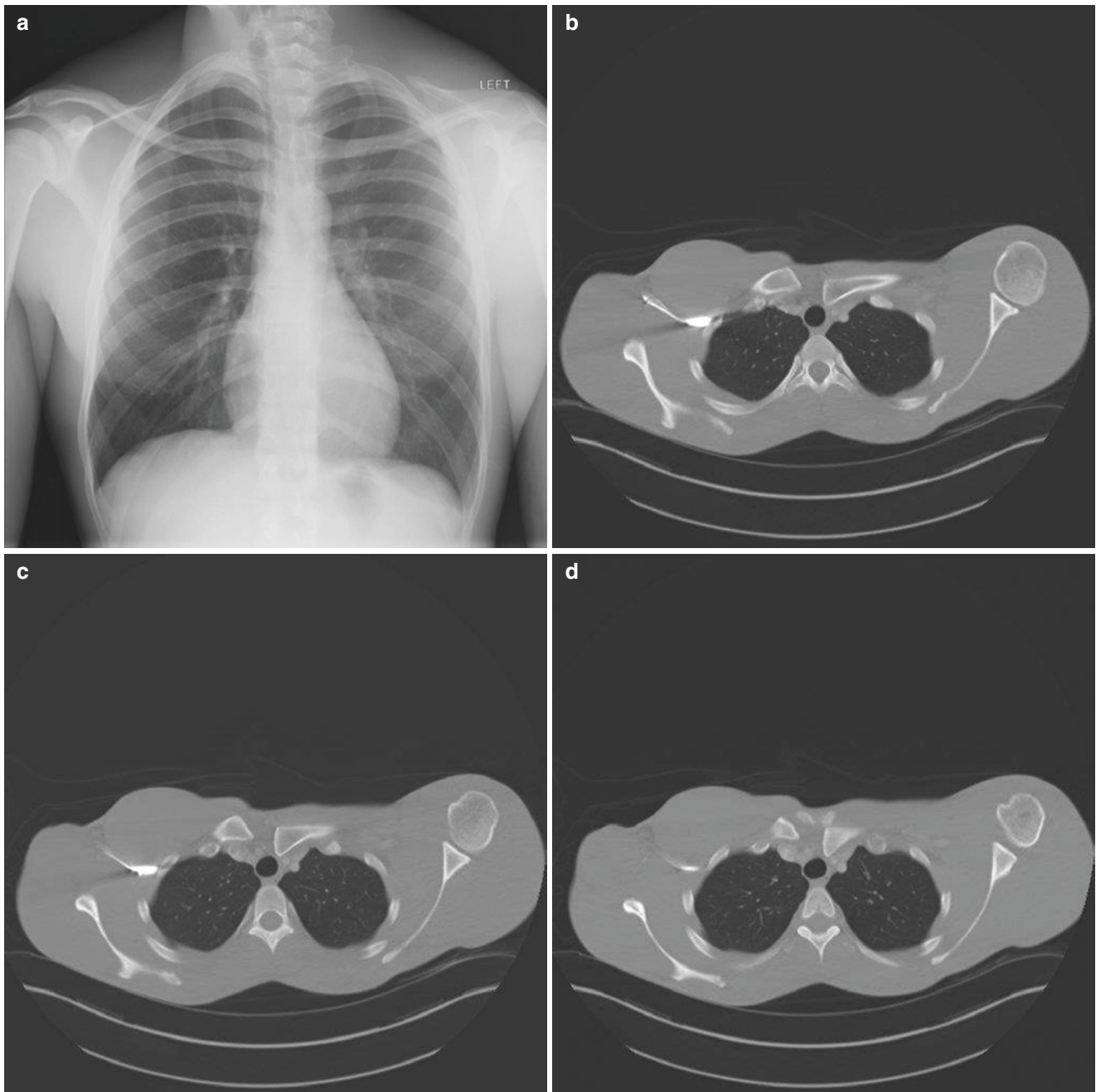
**Fig. 4.54** Reduced left SC joint (*arrow*)



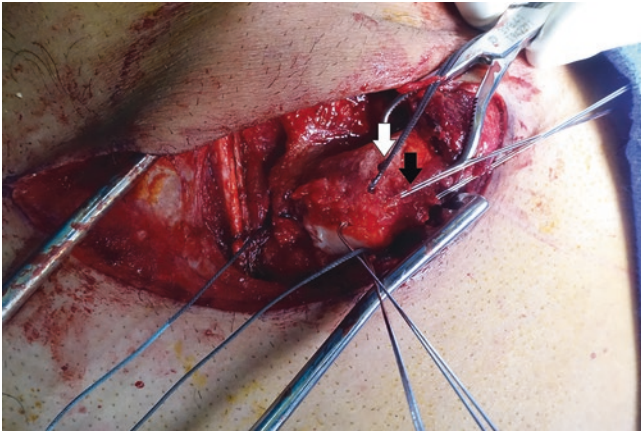
**Fig. 4.55** Wires passed with sutures placed for repair of anterior, posterior, and costoclavicular ligaments



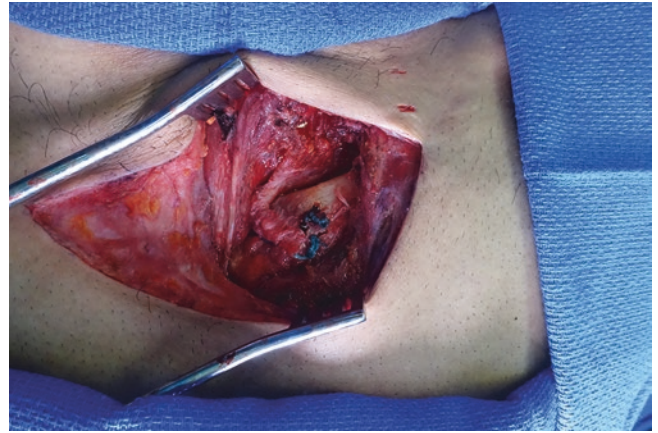
**Fig. 4.56** Sutures tied



**Fig. 4.57** (a) Chest radiograph of left SC dislocation. (b–d) CT scans demonstrating left SC joint posterior dislocation



**Fig. 4.58** Sutures being passed following open reduction of left SC joint, including the posterior ligament (*white arrow*) and anterior ligament (*black arrow*)



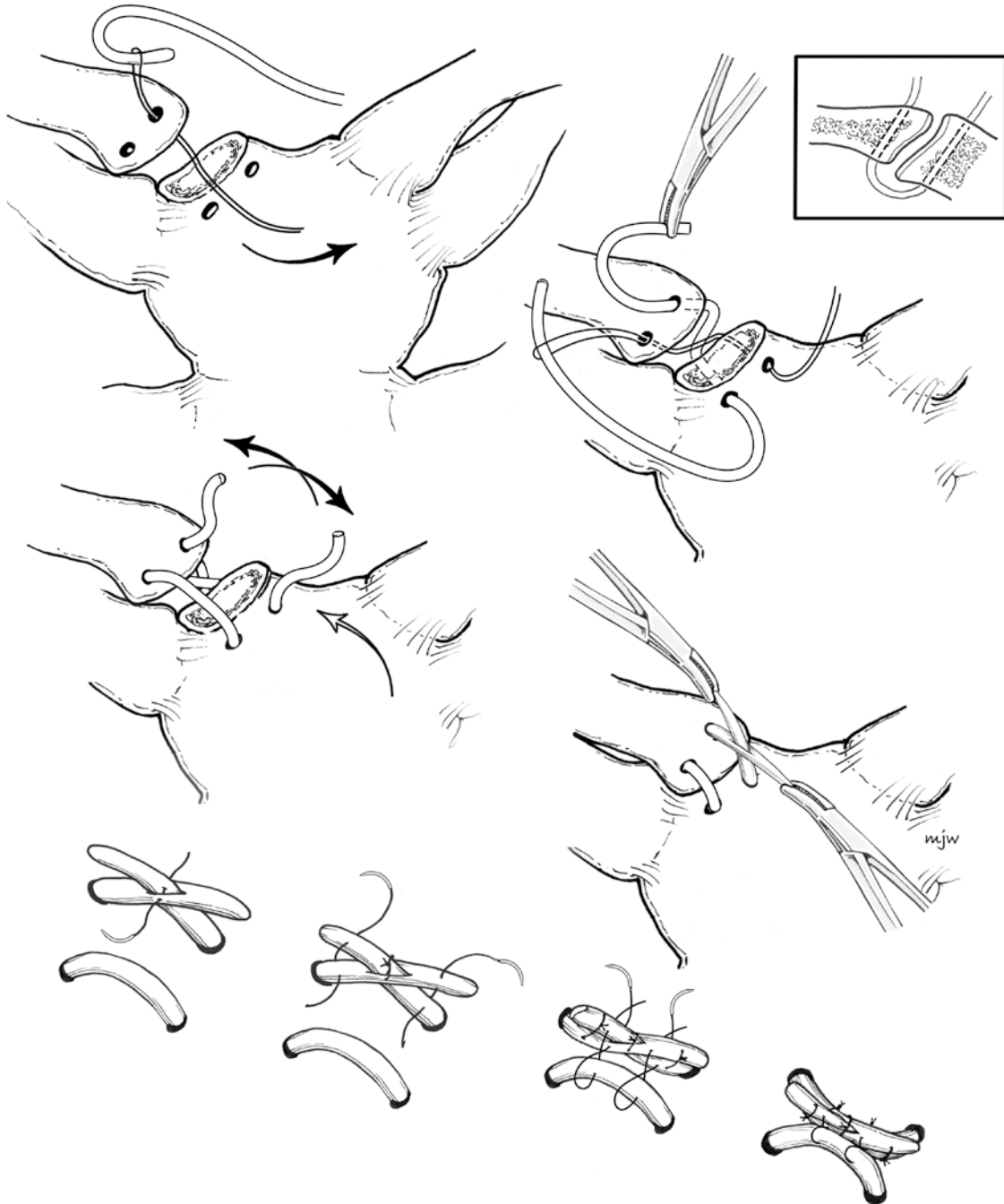
**Fig. 4.59** Clavicle reduced, sutures tied



### 4.2.3 Surgery for Chronic Instability

Some orthopaedic surgeons may resect the medial aspect of the clavicle for a chronic instability or a painful SC joint, but I have found this to be unnecessary. Furthermore, the few patients whom I have seen after this resection have been very unhappy with the result because of persistent pain.

In the chronic scenario, I use a figure-of-eight ligament reconstruction technique, similar to Spencer and Kuhn's technique [11]. However, I orient my crosses in a different fashion, as the major concern is for posterior re-dislocation (Fig. 4.60).



**Fig. 4.60** Diagram of semitendinosus passage for right SC joint reconstruction

Having the limbs parallel posteriorly could potentially pose a situation where another injury may drive the clavicle between the two limbs. To avoid this, I cross the patient's limbs posteriorly to cradle the medial clavicle and have the parallel component anterior. A 2.5-mm drill bit is used to drill two holes in the manubrium and two holes in the medial aspect of the clavicle (Figs. 4.61 and 4.62).

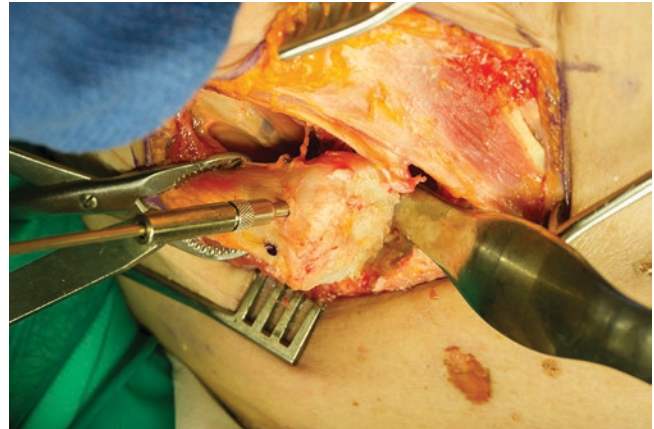


**Fig. 4.61** Example of SC instability reconstruction with all ligaments and meniscus removed



**Fig. 4.62** Right SC joint opened and debrided in preparation for hole drilling

A malleable retractor posterior to the clavicle and manubrium is utilized to prevent plunging towards the mediastinal vessels (Figs. 4.63, 4.64, 4.65, and 4.66).



**Fig. 4.63** A malleable retractor (broad, for demonstration purposes) is placed posterior to the sternal head of the clavicle and manubrium for prevention of plunging



**Fig. 4.64** A malleable retractor (broad, for demonstration purposes) is placed posterior to the sternal head of the clavicle and manubrium for prevention of plunging





**Fig. 4.65** A malleable retractor (broad, for demonstration purposes) is placed posterior to the sternal head of the clavicle and manubrium for prevention of plunging



**Fig. 4.66** A malleable retractor (broad, for demonstration purposes) is placed posterior to the sternal head of the clavicle and manubrium for prevention of plunging

The holes in the manubrium and the clavicle are enlarged from 2.5 to 3.5 mm with the use of a burr; the holes may be further enlarged, depending on the size of the patient and the semitendinosus allograft. Using 24-gauge wire in a loop as a tendon passer, the wire is passed from posterior to anterior, with the first pass through the lateral clavicle superior hole (Fig. 4.67).

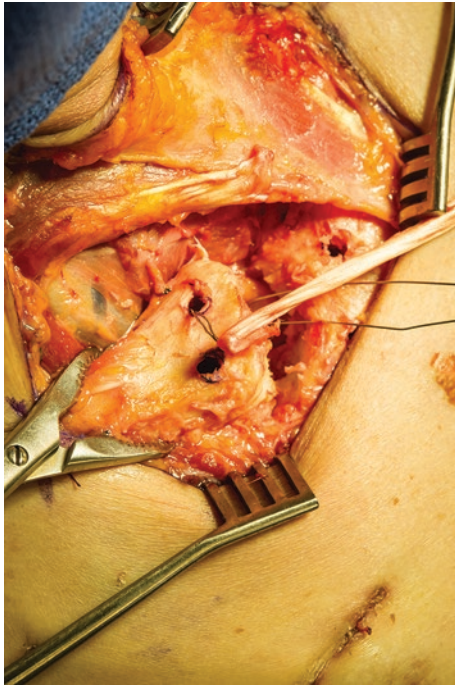
The superior proximal limb of the graft is then passed from anterior to posterior using the 24-gauge wire (Figs. 4.68, 4.69, and 4.70).



**Fig. 4.67** Wire through superior clavicle hole, passed posterior to anterior

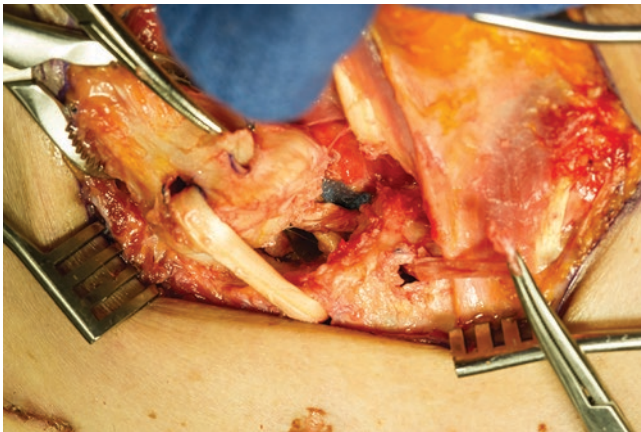


**Fig. 4.68** Semitendinosus allograft

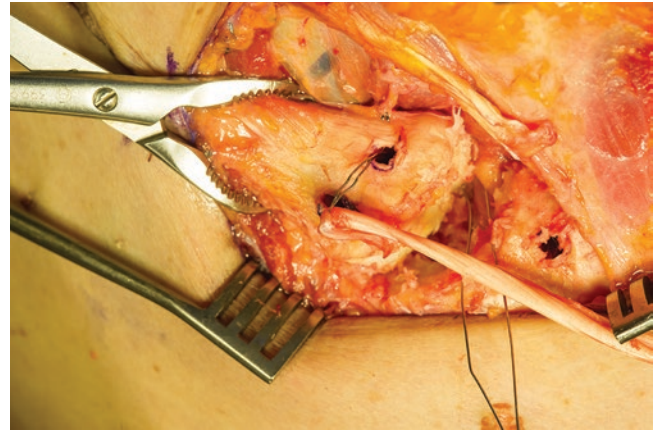


**Fig. 4.69** Semitendinosus in wire

The graft is then delivered anteriorly thru the distal manubrial hole. The next pass is the manubrial free-end, passed anterior to posterior in the distal clavicle hole. Finally, the free end is passed posterior to anterior in the proximal medial manubrium hole (Fig. 4.71).



**Fig. 4.71** Semitendinosus passes completed. The blue background demonstrates the posterior limb crossing



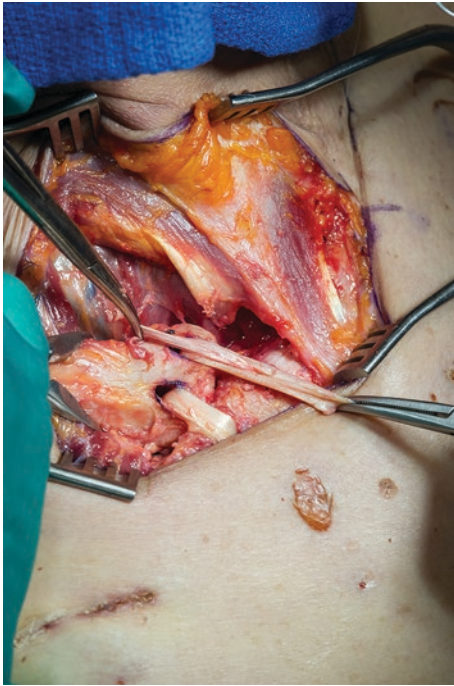
**Fig. 4.70** Semitendinosus in wire

The two superior free ends are single-weaved. The reduction is held with a lion jaw or lobster claw, tension being applied to the limb of the semitendinosus allograft, and the tendon is then weaved through the other end using a tendon weaver (Figs. 4.72, 4.73, and 4.74).



**Fig. 4.72** One limb weaved through the other limb





**Fig. 4.73** One limb weaved through the other limb



**Fig. 4.74** One limb weaved through the other limb

Suturing is performed with a figure-of-eight #5 Ethibond Excel®. (Figs. 4.75, 4.76, 4.77, 4.78, 4.79, and 4.80).



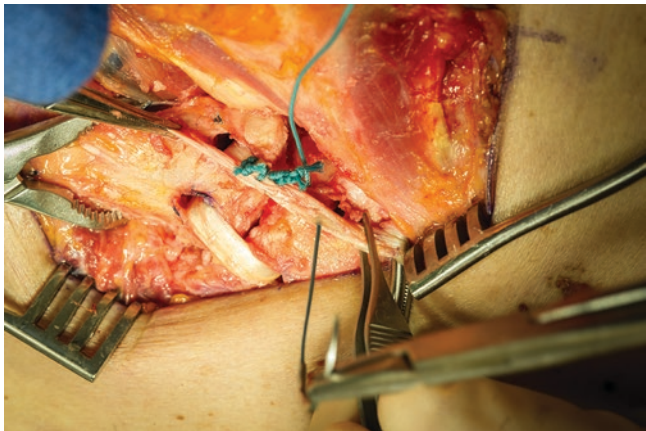
**Fig. 4.75** #5 Ethibond Excel® suture



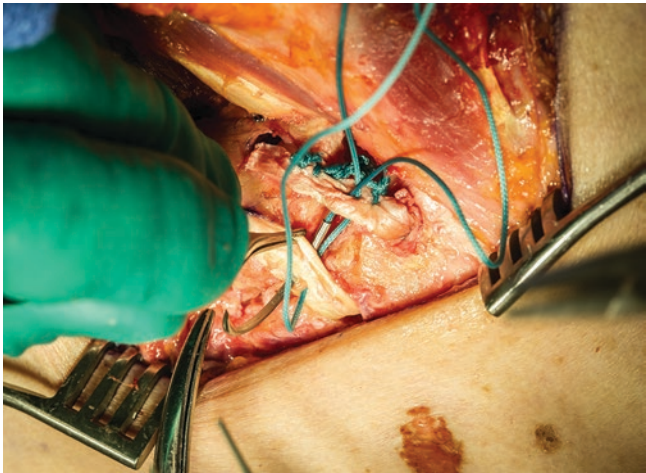
**Fig. 4.76** #5 Ethibond Excel® suture



**Fig.4.77** #5 Ethibond Excel® suture reinforcing ends of graft



**Fig.4.78** #5 Ethibond Excel® suture reinforcing ends of graft



**Fig.4.79** Parallel limbs sutured together



**Fig.4.80** Parallel limbs sutured together



This is reinforced on either end, side-to-side with #5 Ethibond Excel®; the remaining capsular component is then oversewn with 2-0 PDS®. This technique does create somewhat of a bump or fullness, so the patient needs to be counseled that there may be fullness anteriorly, reminiscent of an anterior dislocation (Figs. 4.81 and 4.82).



**Fig. 4.81** SCM repositioned over reconstruction

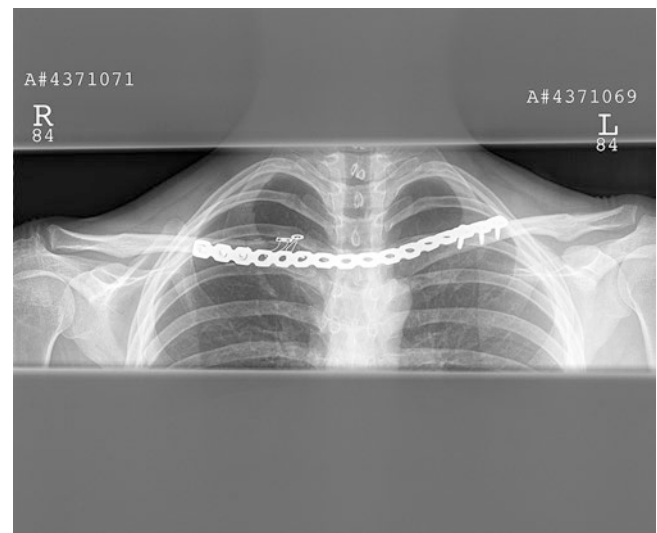


**Fig. 4.82** SCM repositioned over reconstruction

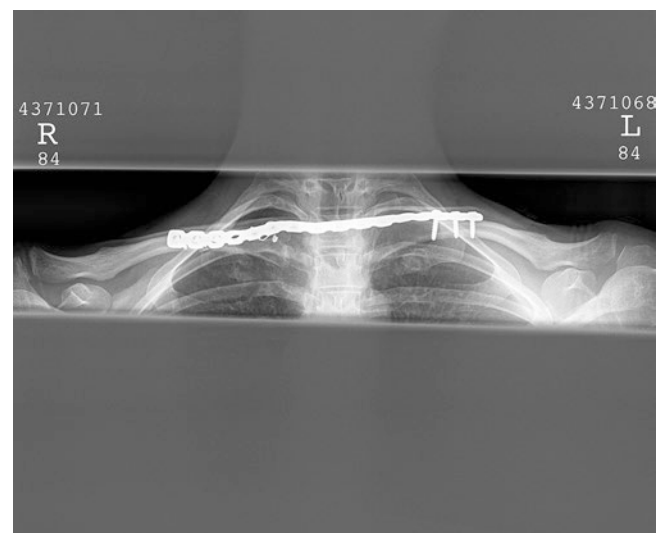
The closure is then carried out with 2-0 Vicryl™, 4-0 Vicryl™, and 3-0 Prolene®, and a medium HemoVac™ drain. The patient's arm is placed in a sling, which must be worn at all times for 6 weeks. Patients may perform elbow range of motion in a supportive fashion. Active range of motion begins at 6 weeks, with strengthening at 8 weeks and weight-bearing at 3 months.

#### 4.2.4 Treatment of Fracture Dislocations

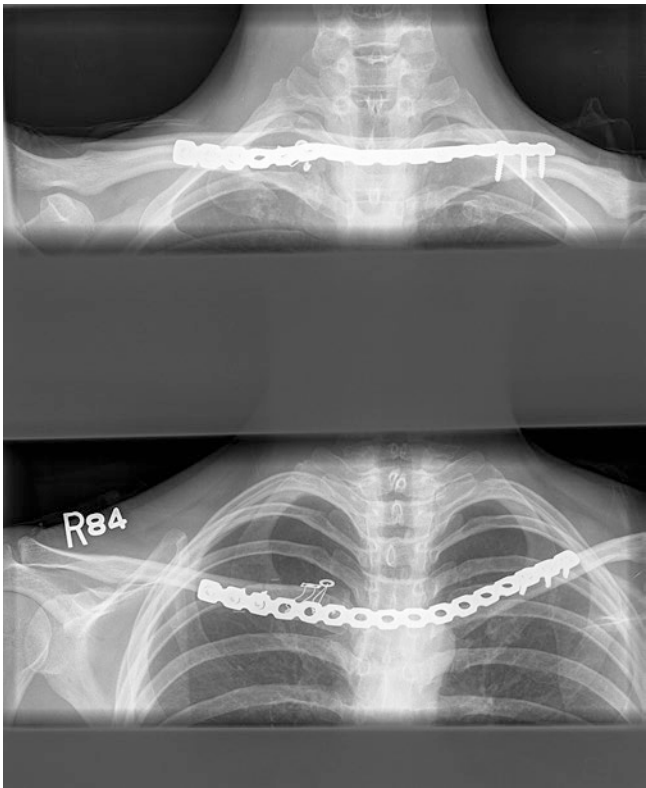
Fracture dislocations are treated with an approach similar to the approach above, but fixation may be performed with either interosseous wires, screw fixation, or clavicle-to-clavicle plate provisional fixation, depending on the fragment size (Figs. 4.83, 4.84, 4.85, and 4.86).



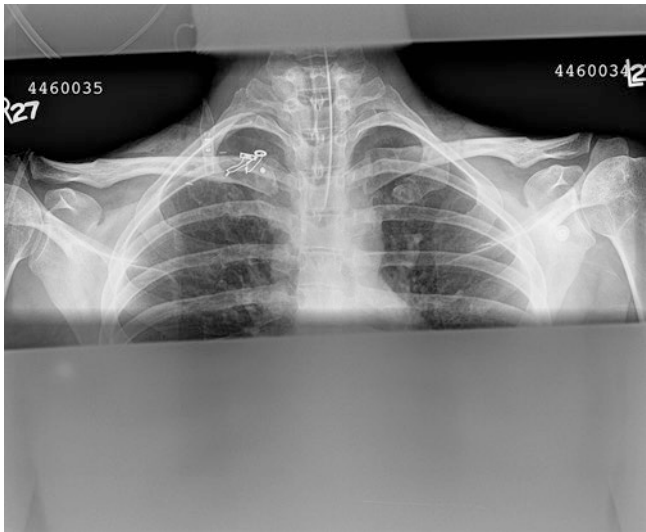
**Fig. 4.83** AP radiograph showing clavicle-to-clavicle fixation following fixation of case in Fig. 4.9



**Fig. 4.84** Lordotic radiograph view



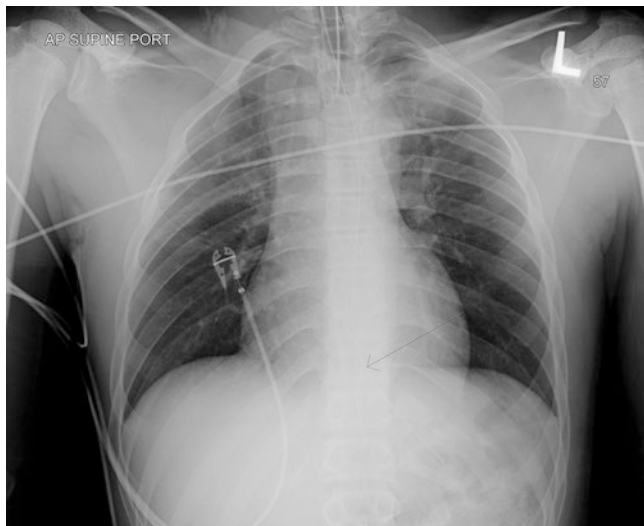
**Fig. 4.85** View before hardware removal



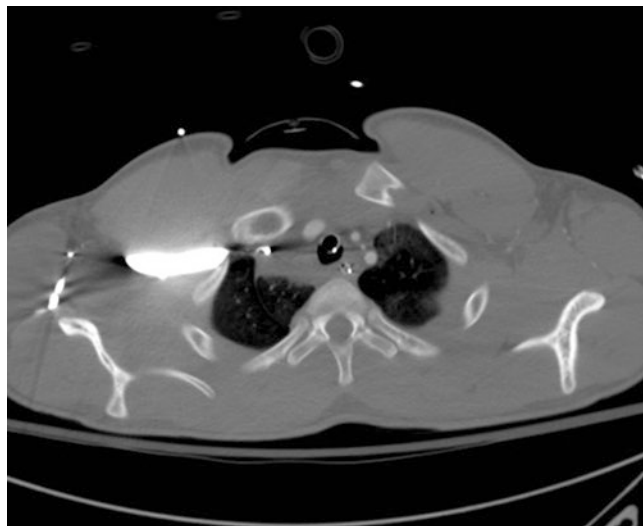
**Fig. 4.86** Hardware removal

Internal fixation with Kirschner wires (K-wires) is not used, as it has been associated with some catastrophic complications [12–15]. Fracture dislocations in adolescents can

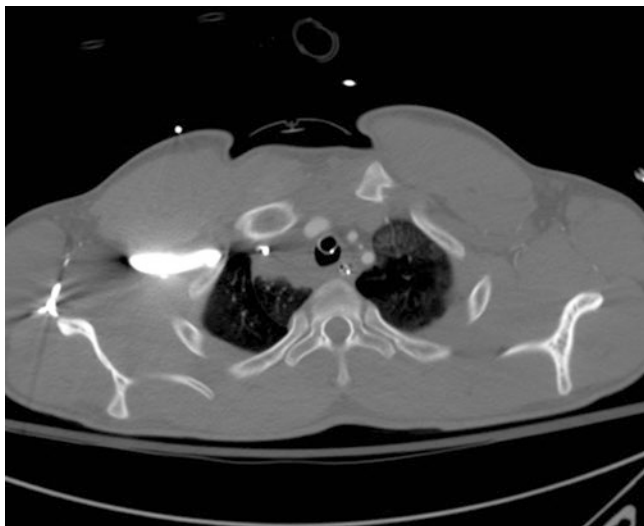
be repaired with sutures through drill holes, either through the fracture fragments or the epiphysis (Figs. 4.87, 4.88, 4.89, 4.90, 4.91, 4.92, 4.93, and 4.94).



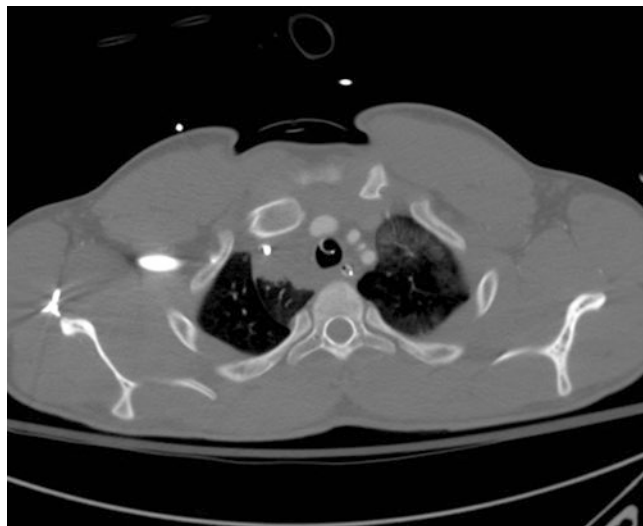
**Fig. 4.87** Chest radiograph of right medial clavicle physeal fracture (Courtesy of Dr. Raymond Pensy)



**Fig. 4.88** CT scan of medial clavicle

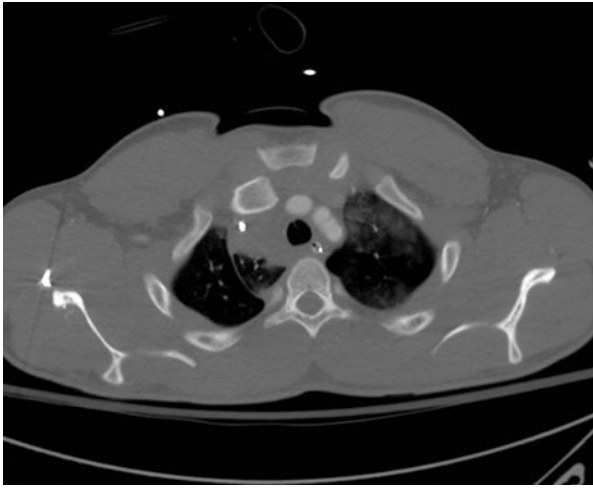


**Fig. 4.89** Posterior dislocation of right clavicle

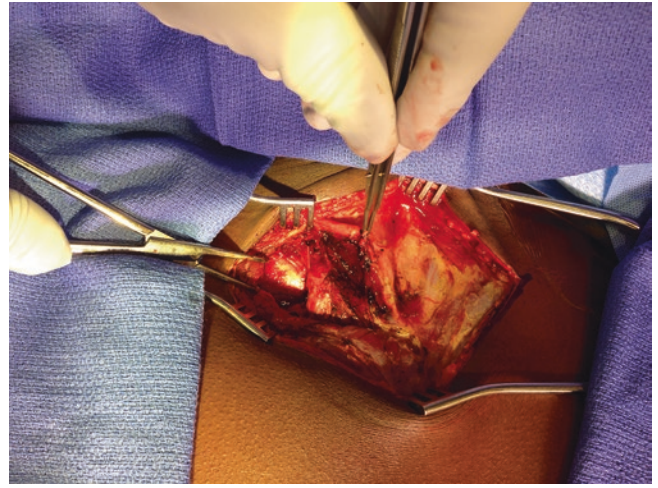


**Fig. 4.90** Posterior dislocation of right clavicle

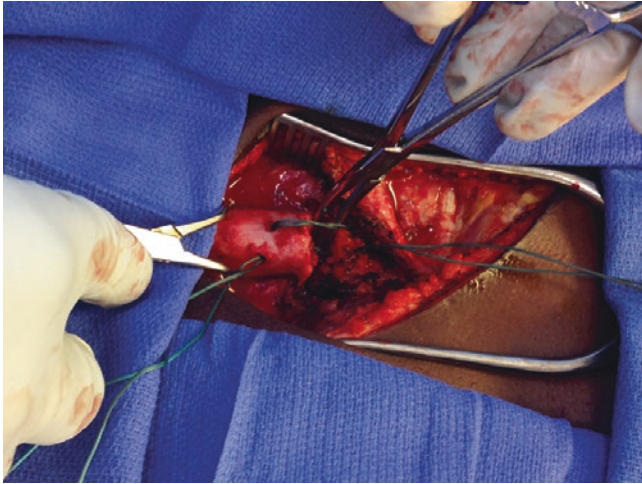




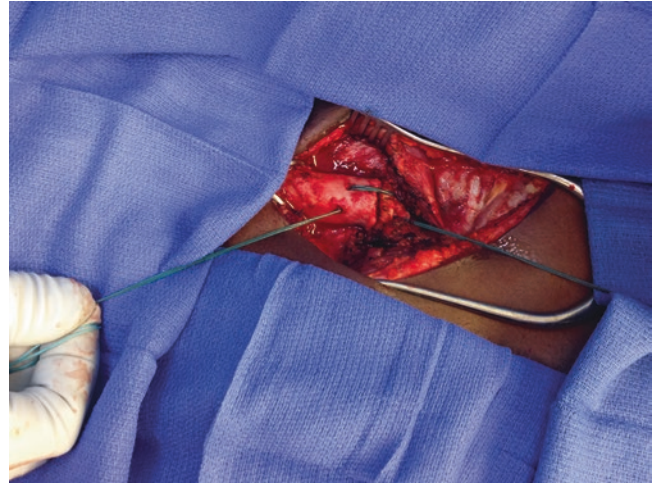
**Fig. 4.91** Posterior dislocation of right clavicle



**Fig. 4.92** Reduction of medial clavicle, *right side*



**Fig. 4.93** #5 Ethibond Excel® suture being passed through drill holes in clavicle and epiphysis



**Fig. 4.94** #5 Ethibond Excel® suture being tensioned

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## 5.1 Indications *versus* Justifications for Clavicle Fixation

The assault unleashed upon unsuspecting clavicles as a result of recent publications is mind-boggling. More than any fracture treatment, clavicle fixation falls into the category of justification rather than indication. As surgeons, we must now contend with the recently reported phenomenon of upright X-rays, as if patients with clavicle fractures just now—for the

first time in history—started standing up, with resultant fracture displacement [1]. This “phenomenon” and others are being used to justify surgical intervention on clavicle fractures. As the many publications [2–13] started to appear, I followed due diligence in reviewing them, including the Canadian paper [9], in which 49 patients who were treated nonoperatively experienced 7 nonunions and 9 malunions, for a 33% rate of clavicle issues (Table 5.1).

**Table 5.1** Summary of clavicle studies

Author	Year	Patients	Results
Nordquist <i>et al.</i> [2]	1998	225 midshaft fractures, non op; 197 figure-8 splint, 3 weeks 24 immediate ROM	185 asymptomatic, 39 moderate pain 125 healed normally 53 malunion (40 good) 7 (3.8%) nonunion (3 good)
Wick <i>et al.</i> [3]	2001	39 patients, malunion/delayed union	Recommended ORIF in symptomatic patients (> 2 cm shortening/ no callus)
Robinson <i>et al.</i> [4]	2004	868 patients	Nonunion @ 24 weeks: 6.2% overall; 8.3% medial; 4.5% diaphyseal; 11.5% lateral Risk factors for nonunion: lack of cortical apposition, female sex, comminution, advanced age
Nowak <i>et al.</i> [5]	2004	245 patients, 9–10 y follow-up, non-op	112 (54%) complete recovery 96 (46%) sequelae Strongest radiographic predictor: no bone contact; not shortening or location of fracture
Zlowodzki <i>et al.</i> [6]	2005	Review/evidence-based 2144 fractures	30% requested hardware removal
McKee <i>et al.</i> [7]	2006	30 patients, non op, 55 mo mean follow-up	Decreased strength/endurance, flexion, abduction, external and internal rotation Mean Constant score, 71 points; DASH score, 24.6 (residual deficits)
Lazarides and Zafiroopoulos [8]	2006	132 middle third clavicle fractures, non op	34 (26%) dissatisfied Unsatisfactory results associated with final shortening >18 mm (male), >14 mm (female)

(continued)



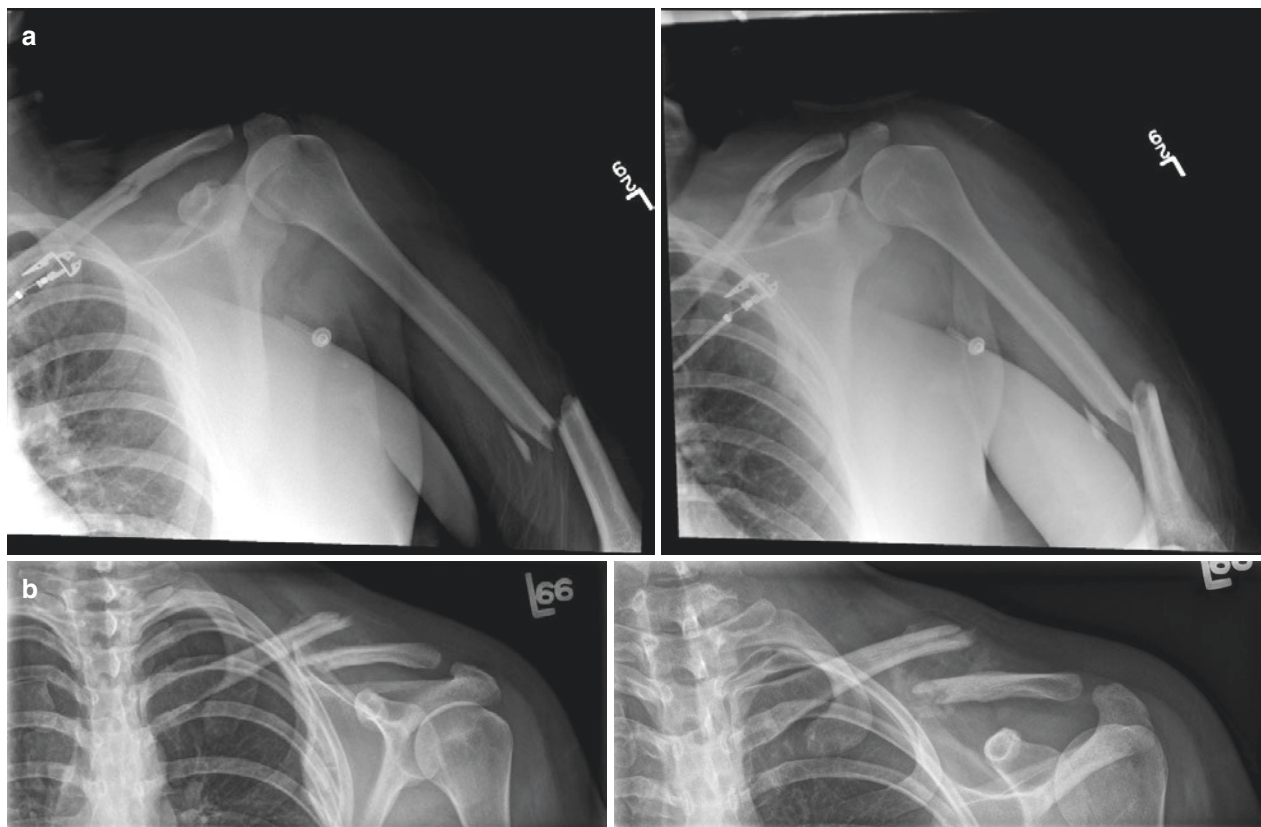
**Table 5.1** (continued)

Author	Year	Patients	Results
Canadian Orthopaedic Trauma Society [9]	2007	Multi-center: 132 pts completely displaced midshaft fracture: 65 non op, 67 op	Op group had 10 point higher Constant score, 11 points lower DASH Symptomatic: 7/49 nonunion; 9/49 malunion Hardware removal: 5/62
Potter <i>et al.</i> [10]	2007	15 acute ORIF, 15 delayed fixation for nonunion or malunion	No difference in strength, flexion, abduction, external or internal rotation Constant score > acute DASH—no difference Subtle decrease in endurance strength with delay
Altamimi <i>et al.</i> [11]	2008	132 pts; 65 non op, 67 op	Op Constant/DASH improved at all points Radiographic union: Op, 16.4 weeks; non op, 28.4 weeks Symptomatic malunion: 9/65
McKee <i>et al.</i> [12]	2012	Meta-analysis, 6 studies, 412 pts with displaced midshaft fracture (op vs non op)	Nonunion: 29/200 non op Symptomatic malunion: 17/200 non op; 0/212 op Little evidence of superior long-term functional outcome
Lenza <i>et al.</i> [13]	2013	8 trials: 555 middle-third fractures (op vs non op)	Limited evidence for op effectiveness; recommend treatment on individual basis

DASH disability of the arm, shoulder and hand, ORIF open reduction internal fixation

Over the decades of my work in trauma, I am unable to recall (nor have I seen recorded) any patient complaint about

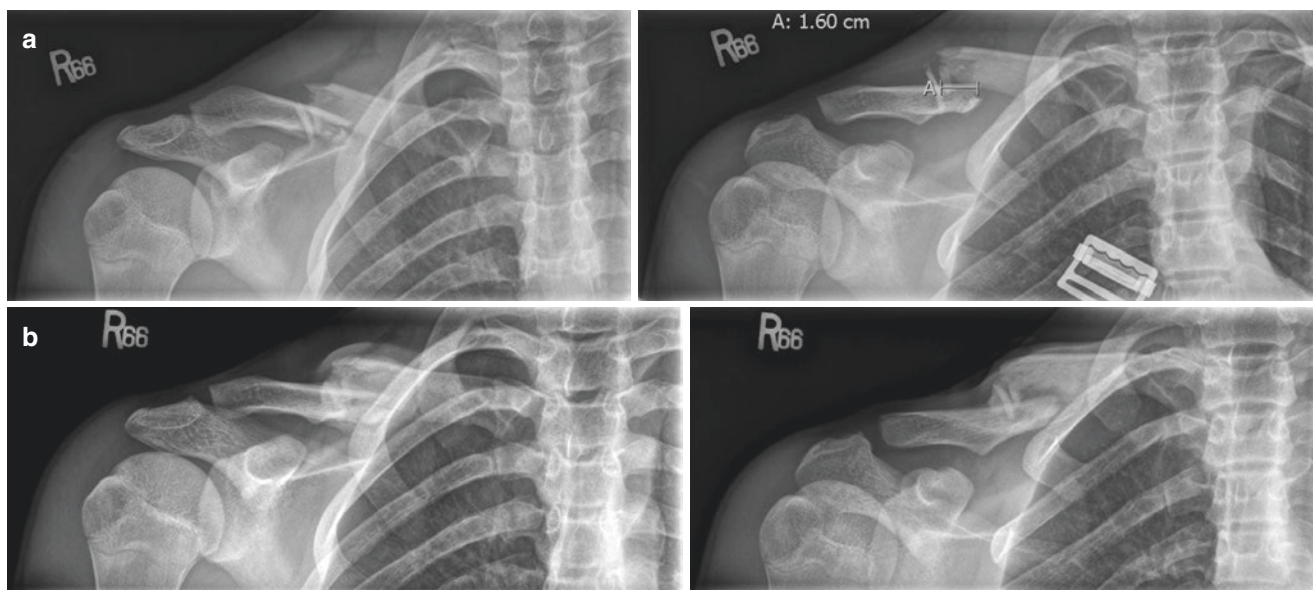
a clavicle malunion that necessitated an osteotomy or intervention (Figs. 5.1 and 5.2).



**Fig. 5.1** (a) Injury radiographs of left clavicle, humerus, radius, and ulna fractures with nonoperative treatment of clavicle and open reduction internal fixation (ORIF) of the humerus, radius, and ulna.

(b) Follow-up healing clavicle fracture with no pain and full shoulder range of motion. (c, d) Follow-up radiographs of shoulder, humerus, radius, and ulna following ORIF

**Fig. 5.1** (continued)



**Fig. 5.2** (a, b) Injury and follow-up radiographs of right clavicle treated nonoperatively, with deformity noted. The patient resumed unrestricted activity at 6 weeks from injury. (A represents a radiologist marking)

### 5.1.1 Functional Activities and Minimal Clinically Important Difference

The idea that the Constant-Murley Shoulder Outcome Score reflects an “indication” for surgical intervention needs to be tempered with the understanding that the difference in the Constant score may not reflect minimal clinically important difference (MCID) in functional activities [14]. Thus, even though a score may reflect some difference, there is ultimately no appreciable clinical difference. The notation that the Constant-Murley score was ten points different and significant throughout was cited by the authors of the Canadian paper [9]. The report seems to show a narrowing of the score as the months passed, however, it does not seem to stand up to that threshold throughout. I realize that this may be an oversimplification that could be seen by some as a misrepresentation of a statistical principle, but I think the concept that a scored outcome may not reflect a functional difference has clinical legs.

Patients do tell me more and more frequently that they want their clavicles fixed. As we all know, our patients are

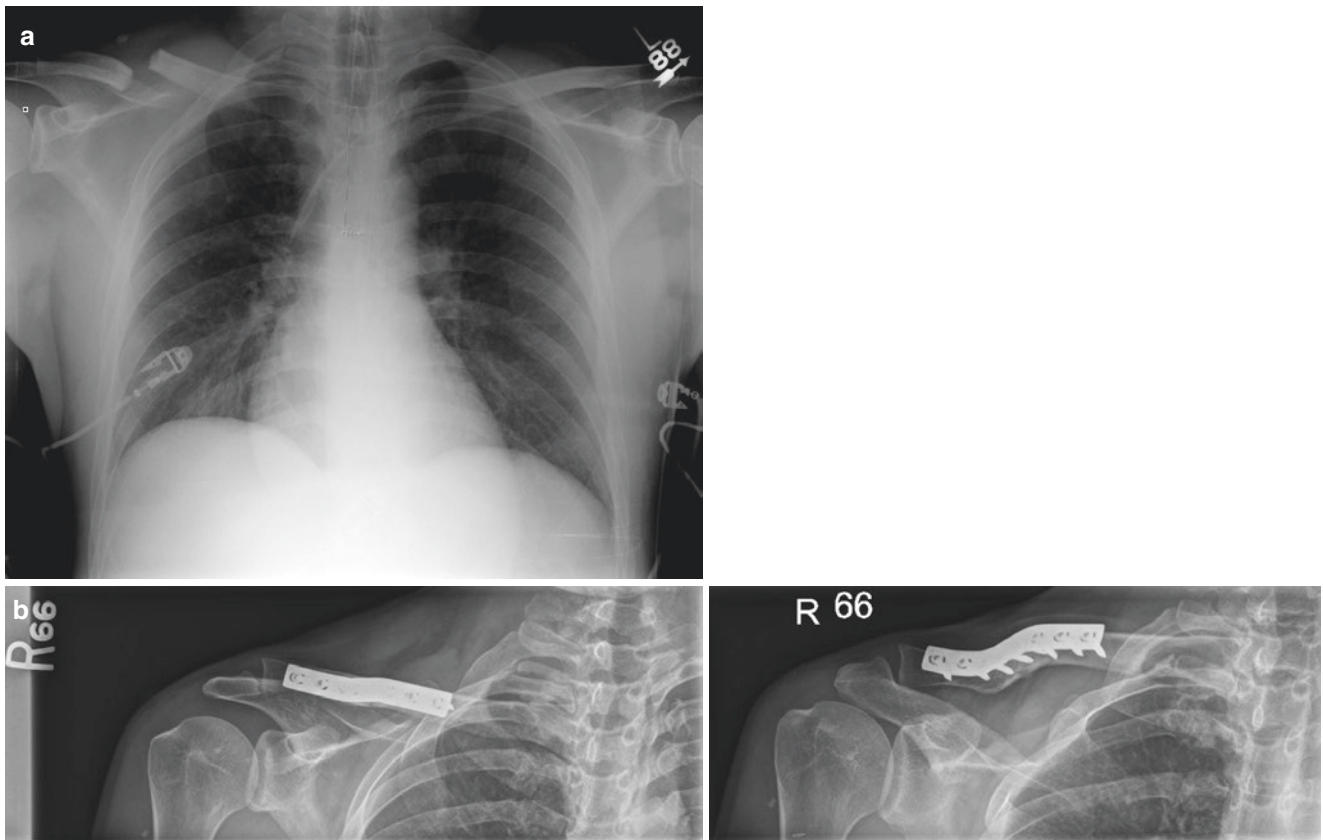
frequently guided by our unintended vocal tones, inflections, and personal opinions. I believe that with the way patients are counseled, and under the influence of electronic media, patients think that clavicle fixation is what they want because they think it offers better outcomes. I believe that more recent studies on acute fractures show that this thinking needs to be questioned. We need to step back some, so that we don’t get swept away by the tsunami of enthusiasm for fixation of clavicle fractures [12, 13].

None of this means that clavicles are not fixed at Shock Trauma, but it is to say that they are fixed in a minority of cases.

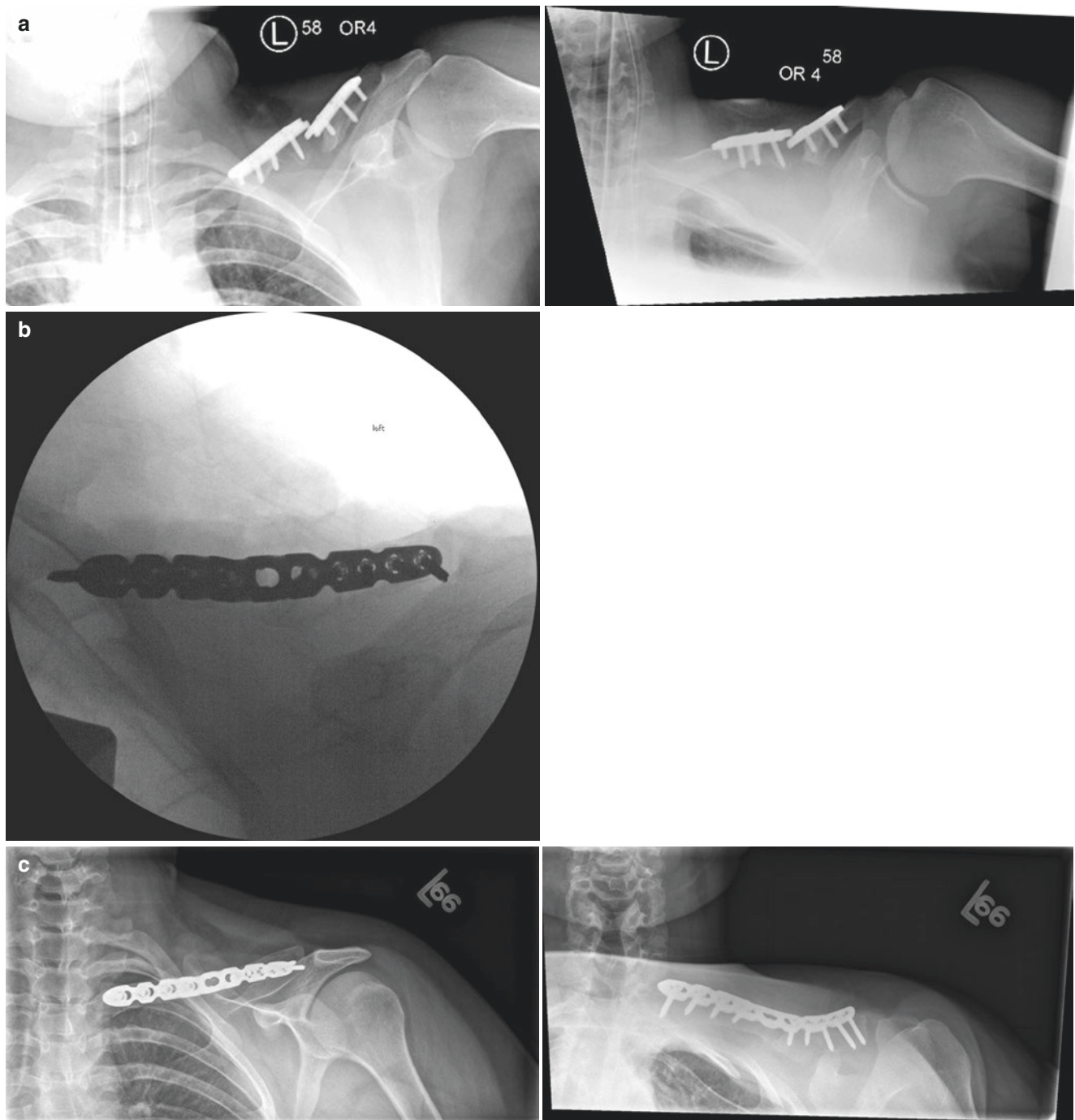
### 5.1.2 Indicators for Open Reduction and Internal Fixation

When I do perform open reduction internal fixation (ORIF) of a clavicle, indications include open fractures (Fig. 5.3), nonunions (Fig. 5.4), and fractures associated with brachial plexus injury (Fig. 5.5).

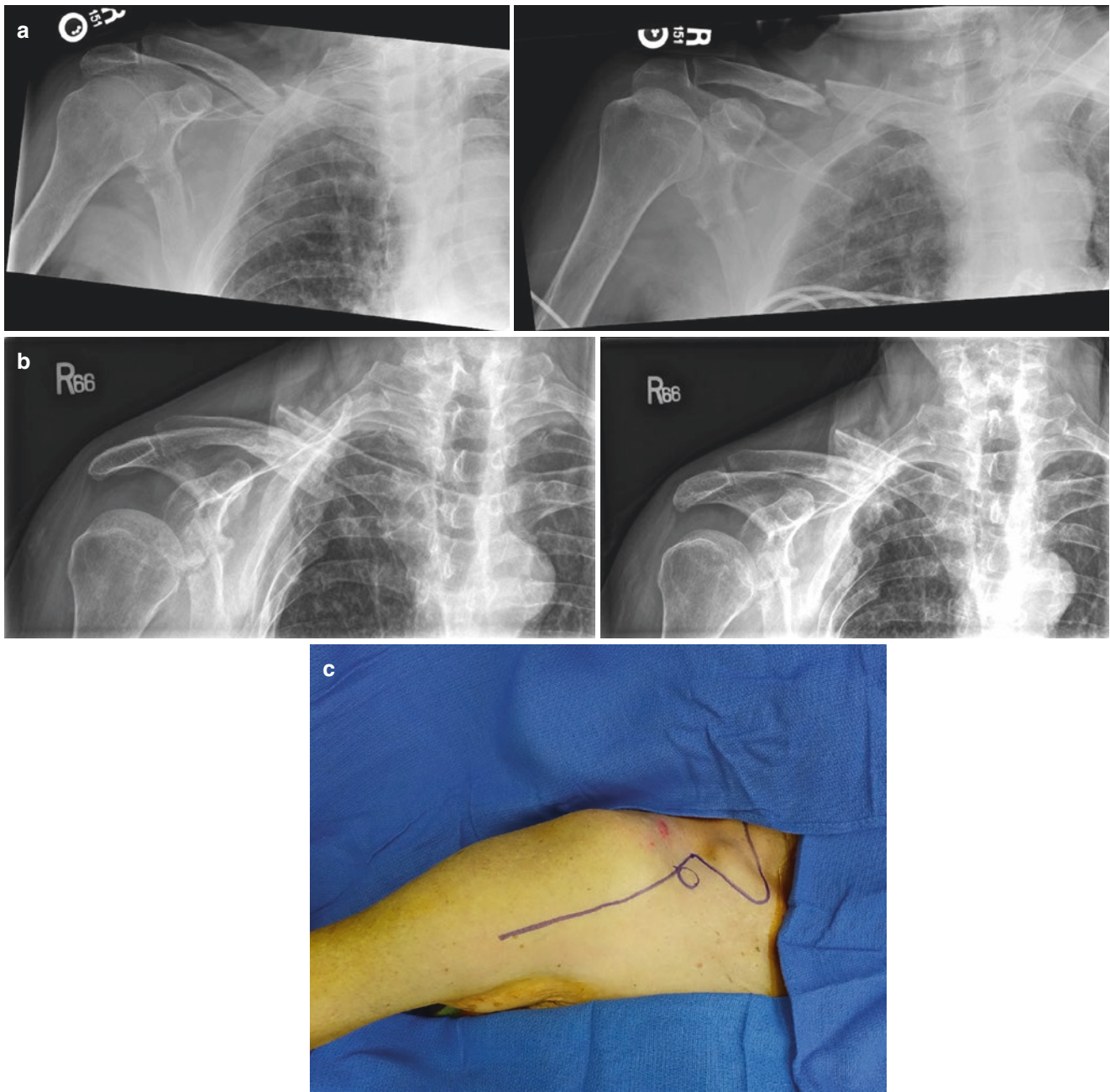




**Fig. 5.3** (a, b) Open clavicle fracture seen on chest radiograph; the patient underwent ORIF



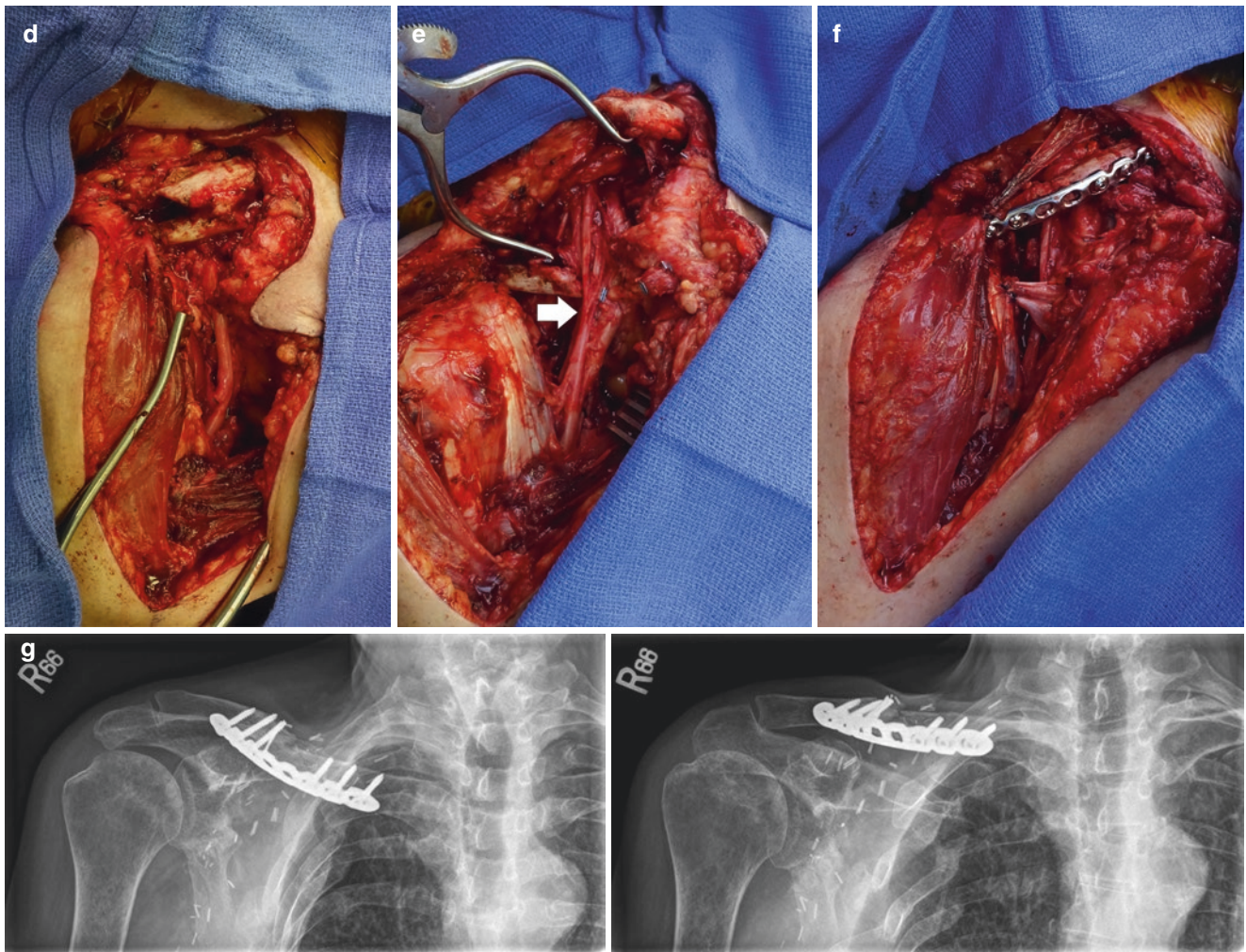
**Fig. 5.4** (a–c) Patient referred for revision ORIF of left clavicle following two previous ORIFs for minimally displaced clavicle fracture



**Fig. 5.5** (a, b) Radiographs of clavicle, which was initially minimally displaced, and then displaced and developed brachial plexus palsy. (c) Incision for approach to right clavicle and brachial plexus. (d) Intraoperative findings of overriding clavicle with compression of plexus, particularly lateral cord prior to clavicle mobilization and neu-

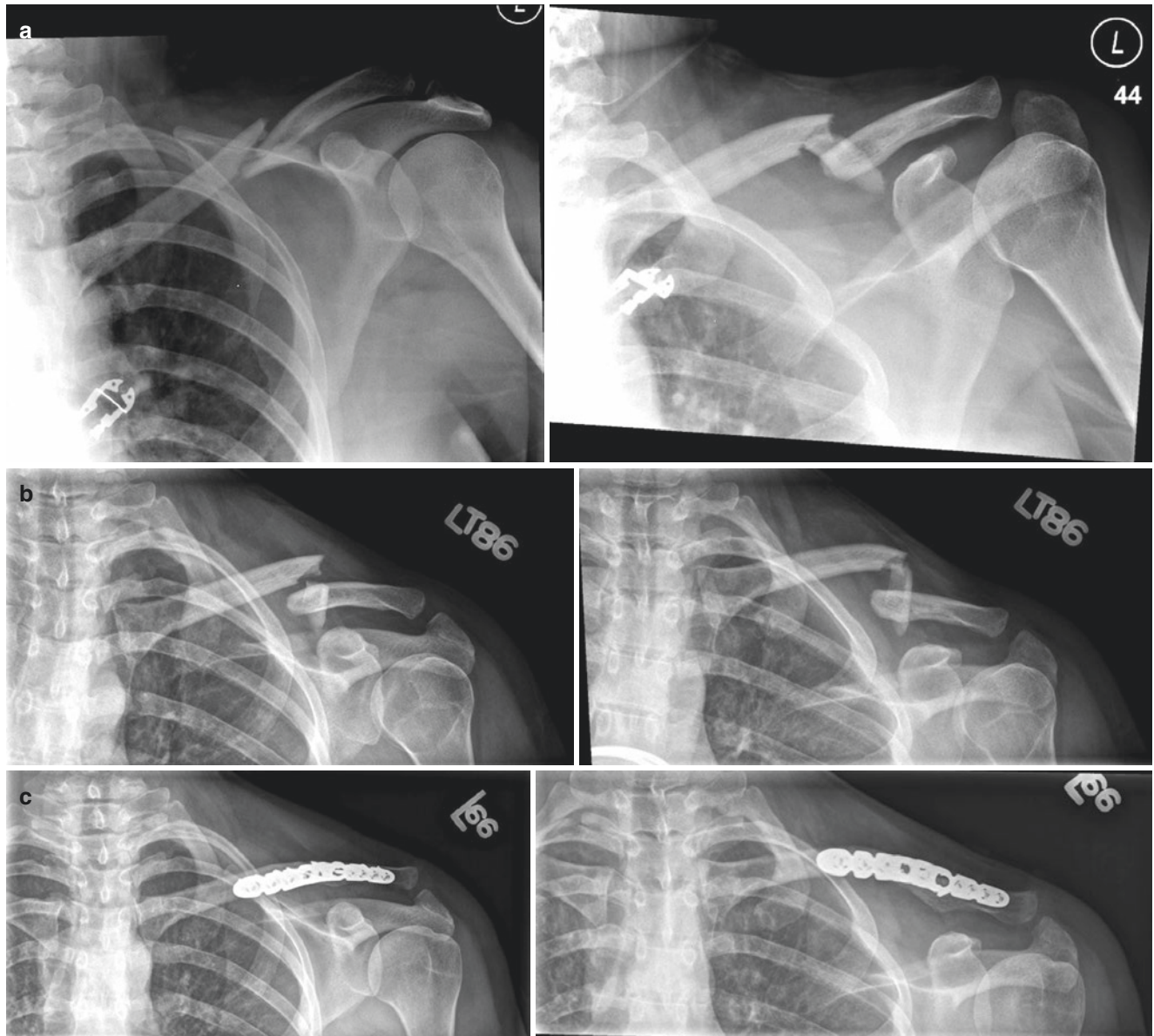
rolysis. (e) Intraoperative findings of overriding clavicle with compression of plexus, particularly lateral cord (arrow) with neurolysis. (f) Intraoperative findings of overriding clavicle with compression of plexus, particularly lateral cord with neurolysis and ORIF. (g) Healed clavicle with return of function





**Fig. 5.5** (continued)

The criteria reported of shortening, overriding, location, gender, and activity will play a factor. Sometimes, because of patient preference after counseling, ORIF is selected (Fig. 5.6).



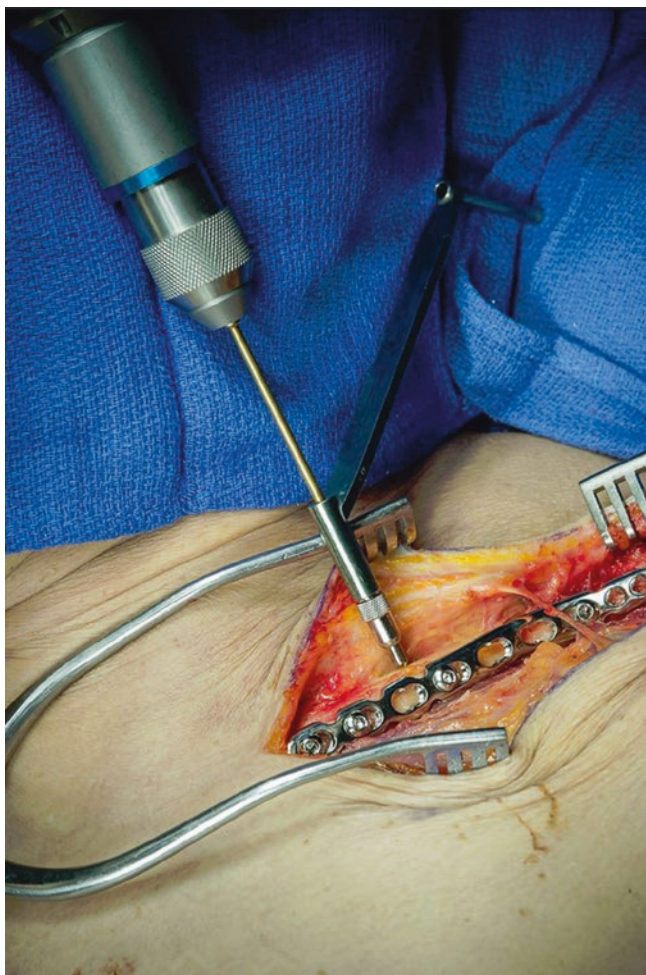
**Fig. 5.6** (a) Radiographs of left clavicle fracture on presentation. (b) Three-week follow-up, at which time the patient requested ORIF. (c) Discharge radiographs after ORIF

I do not feel that the battle cry of floating shoulder or flail chest as an indication for clavicle fixation has ever been borne out [15, 16].



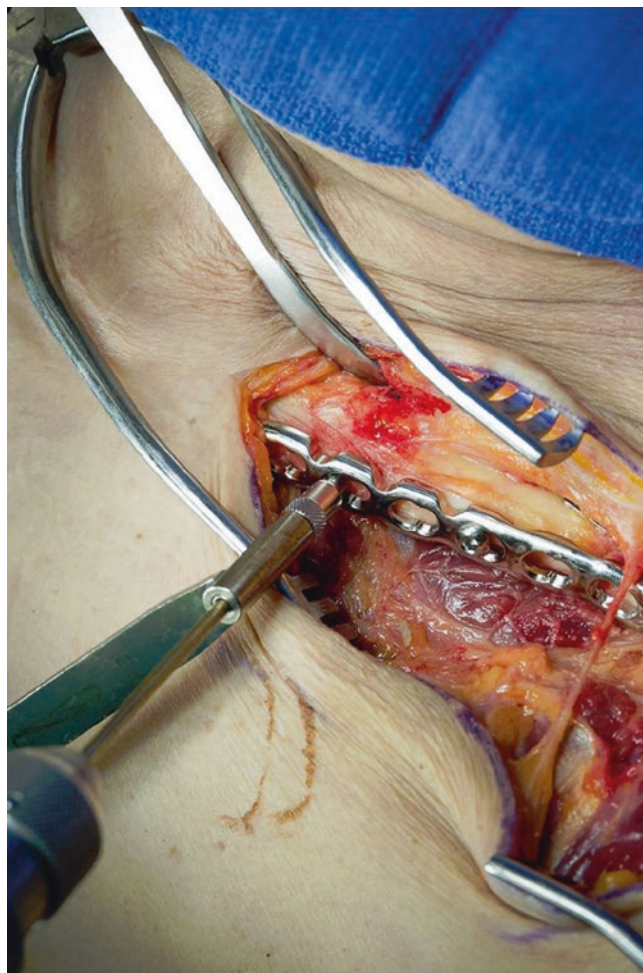
## 5.2 Preferred Operative Approach to Clavicle Fixation

When clavicle fixation is to be performed, I prefer an anterior inferior approach, as opposed to a superior fixation. There are two main reasons I prefer anterior plating. The first reason is purely practical. With a superior plate position, the medial fixation can be very difficult to achieve because the hand with the drill and screwdriver is adjacent to the patient's head; anterior plating allows better control of drilling and screw insertion (Fig. 5.7).



**Fig. 5.7** Hand positioning difficult for superior screws because of abutment against head

Though there is potential for an anterior-posterior drill bit plunge with associated vascular and nerve issues, a strategically placed blunt retractor helps prevent this mishap (Fig. 5.8).



**Fig. 5.8** Retractor placed posterior to clavicle to avoid drill bit plunge

The second reason for anterior plating has to do with the potential for hardware removal due to pain or cosmetic issues related to the prominence of the plate. With the plate in the more anterior position, patients seem to complain less than when a plate is superiorly placed. In other words, with anterior plating, there appears to be less tendency for patients to request that the plate be taken out.

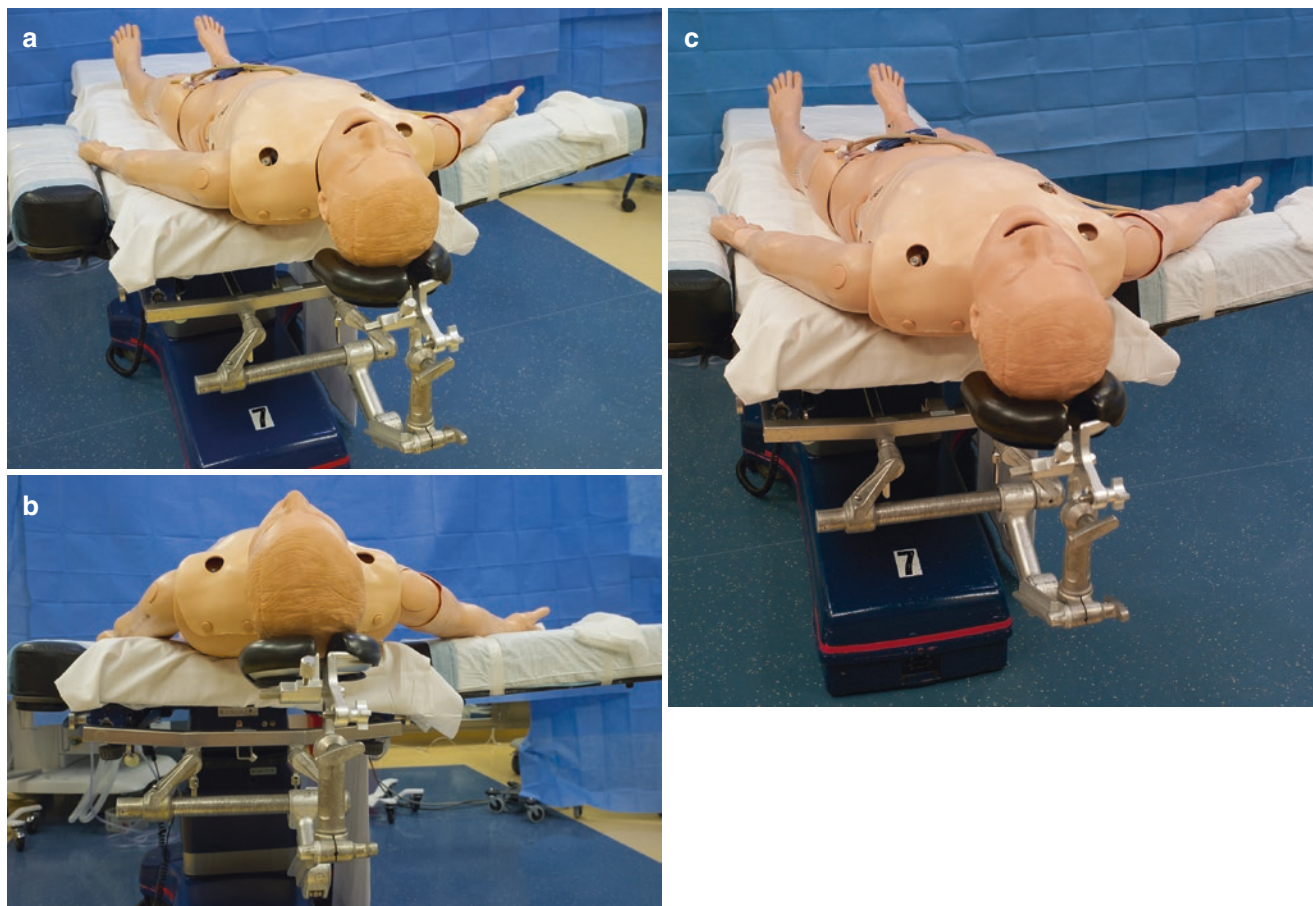


### 5.2.1 Plate Options

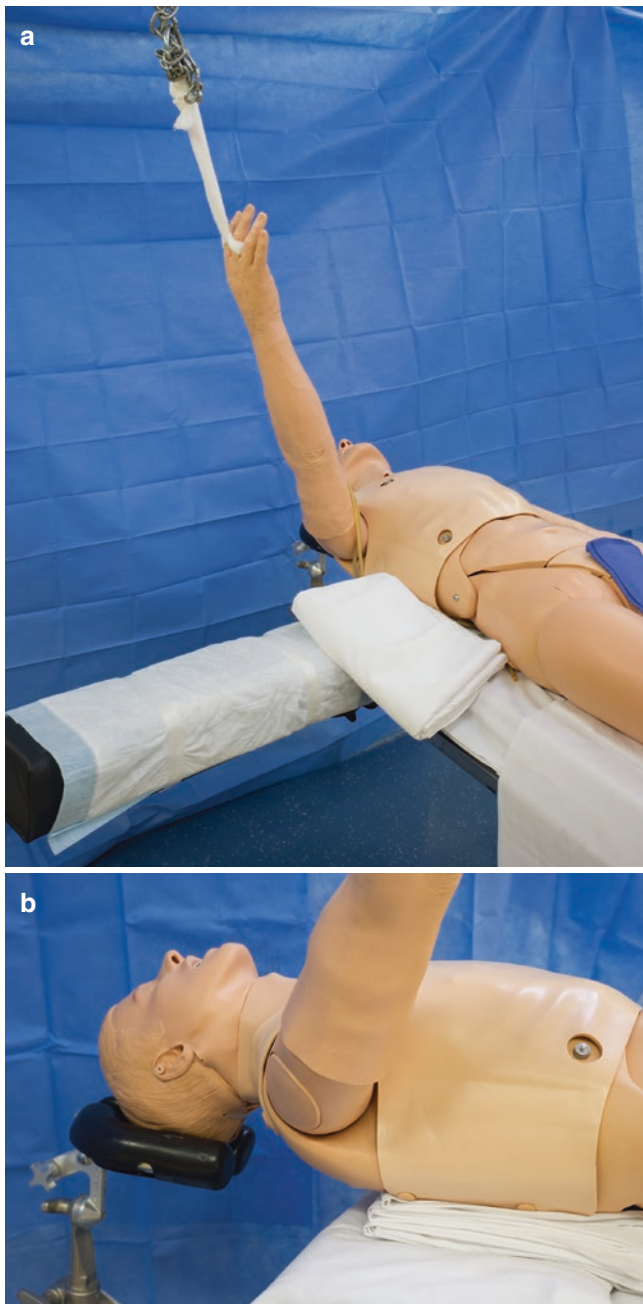
I do not use intramedullary fixation. Typically, I contour a Synthes® 3.5 limited contact dynamic compression plate (LCD-CP™) or use a locking reconstruction plate for mid-shaft fractures. For more lateral fractures, I use the Synthes® precontoured locking plates.

### 5.2.2 Positioning the Patient

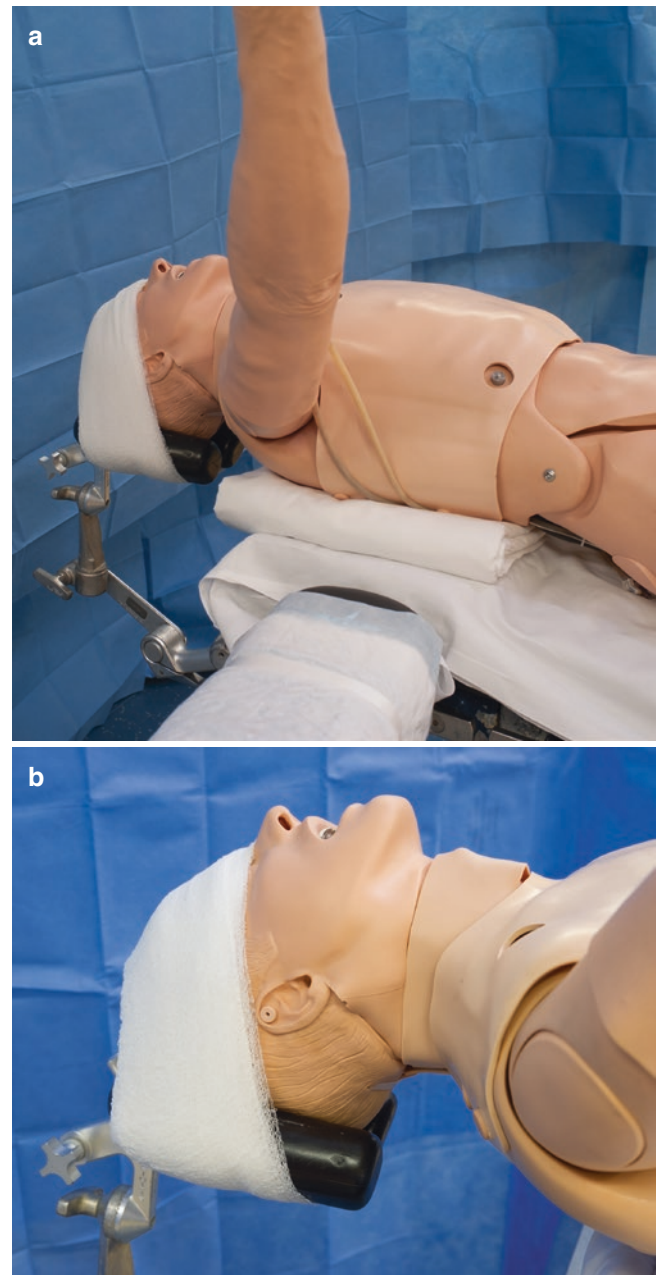
With the patient positioned on a Mayfield headrest, with the head turned to the side opposite the clavicle fracture, I place a two-sheet bump behind the shoulder and use an arm board (Figs. 5.9, 5.10, 5.11, 5.12, 5.13, and 5.14).



**Fig. 5.9** (a–c) Positioning on Mayfield headrest, moved to side of fracture



**Fig. 5.10** (a, b) Two folded sheets behind the shoulder



**Fig. 5.11** (a, b) Head secured with rolled bandage, head rotated to opposite side

**Fig. 5.12** Clinical case with patient positioned in headrest prior to sitting-up position



**Fig. 5.13** Body drape

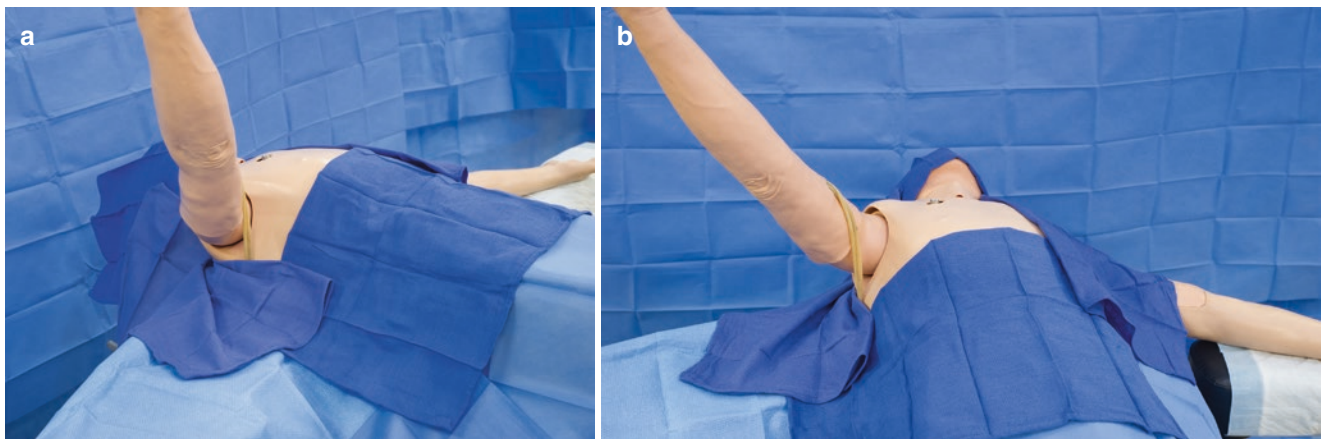




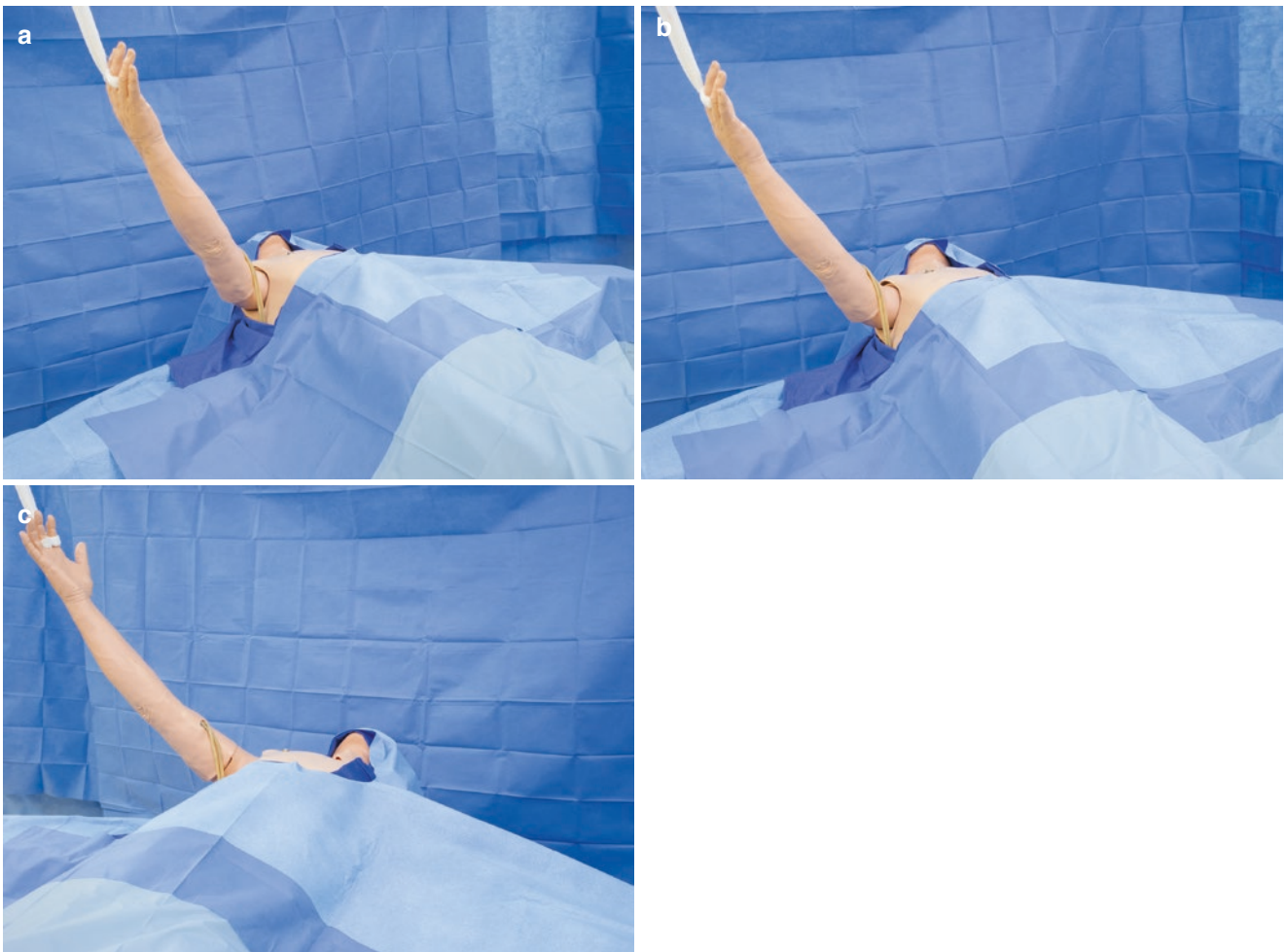
**Fig. 5.14** Three-fourths reinforced drape on arm board, draped with the arm board out, not into the side. Draping with board at the side makes it difficult to get into the axilla and move the arm board if needed



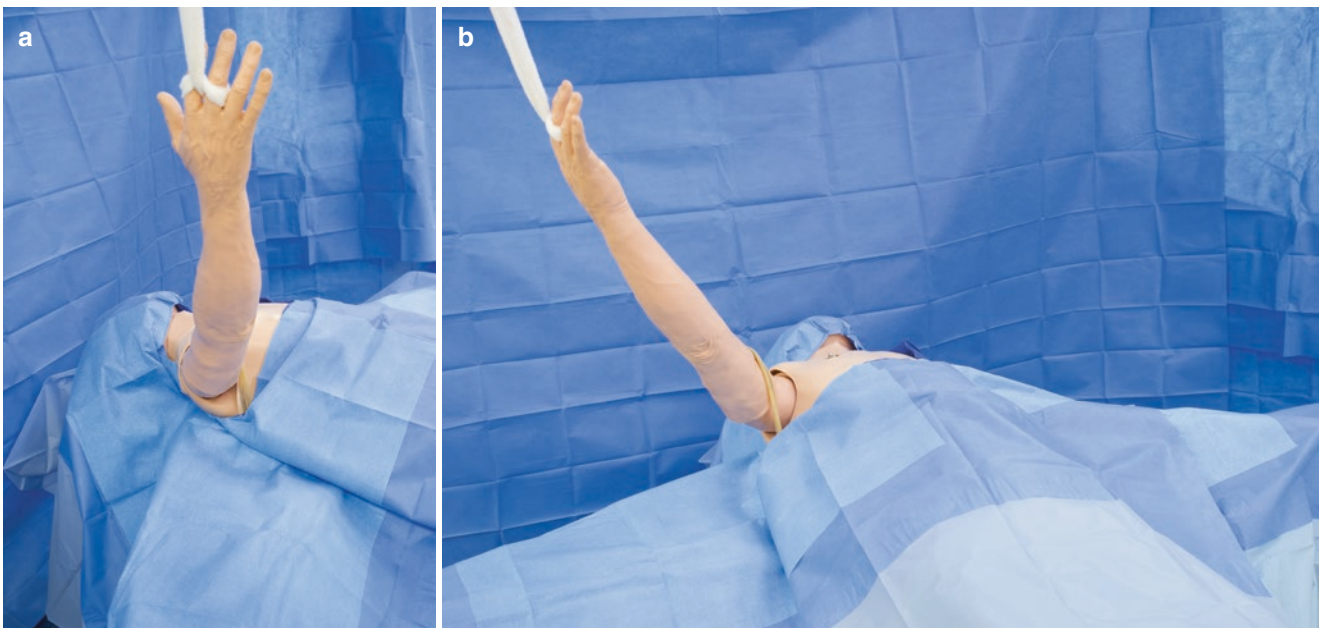
I do not use a hand table. The patient is pre-draped from the ear to the chin to just past the midline inframammary level. The entire extremity is prepped and draped (Figs. 5.15, 5.16, 5.17, 5.18, 5.19, 5.20, and 5.21).



**Fig. 5.15** (a, b) Four-towel perimeter draping

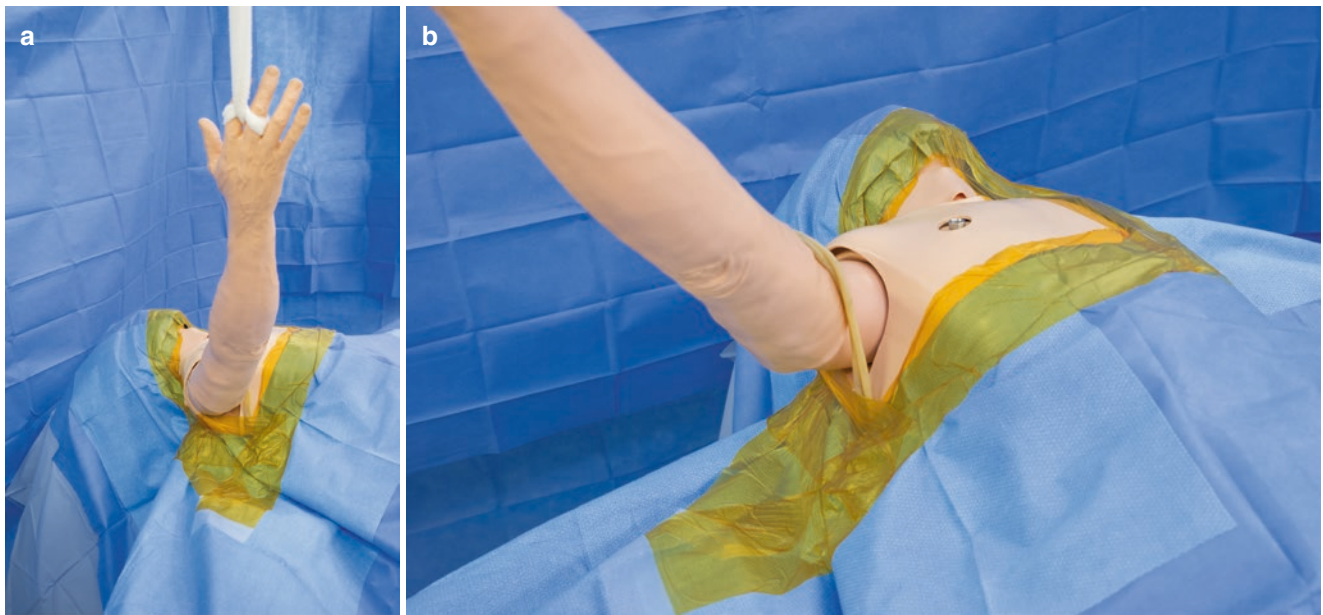


**Fig. 5.16** (a–c) Split drape with tails down

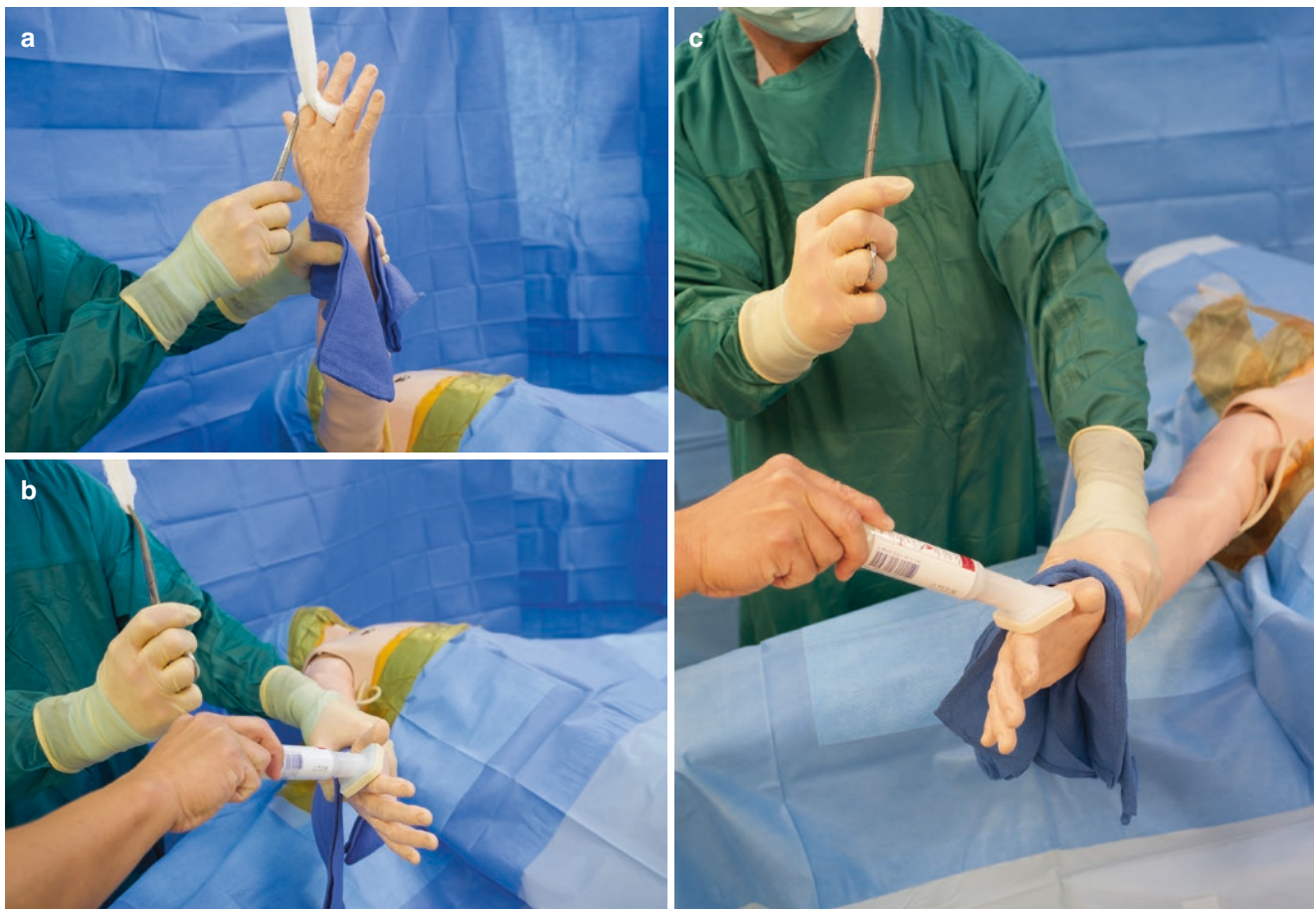


**Fig. 5.17** (a, b) Split drape with tails up



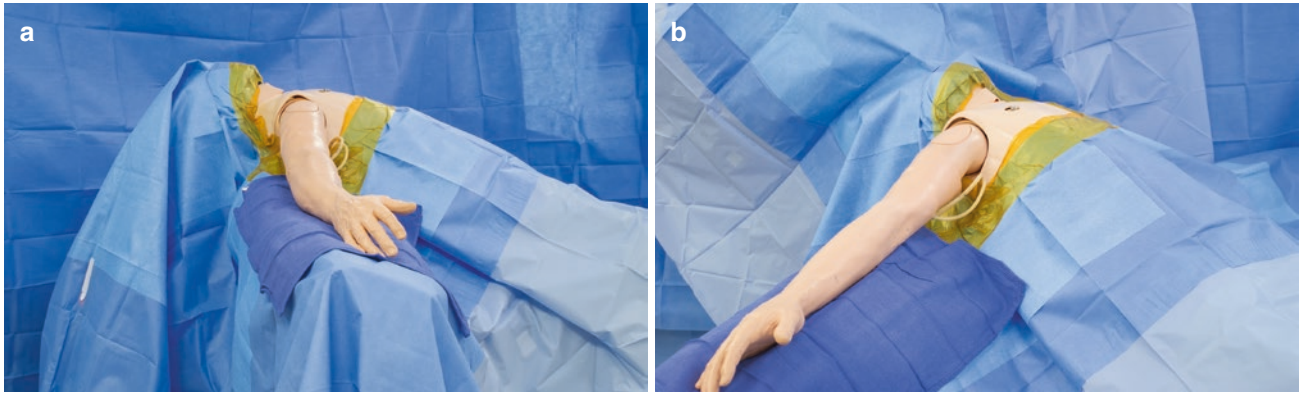


**Fig. 5.18** (a, b) Betadine adherent strips around perimeter to seal drapes

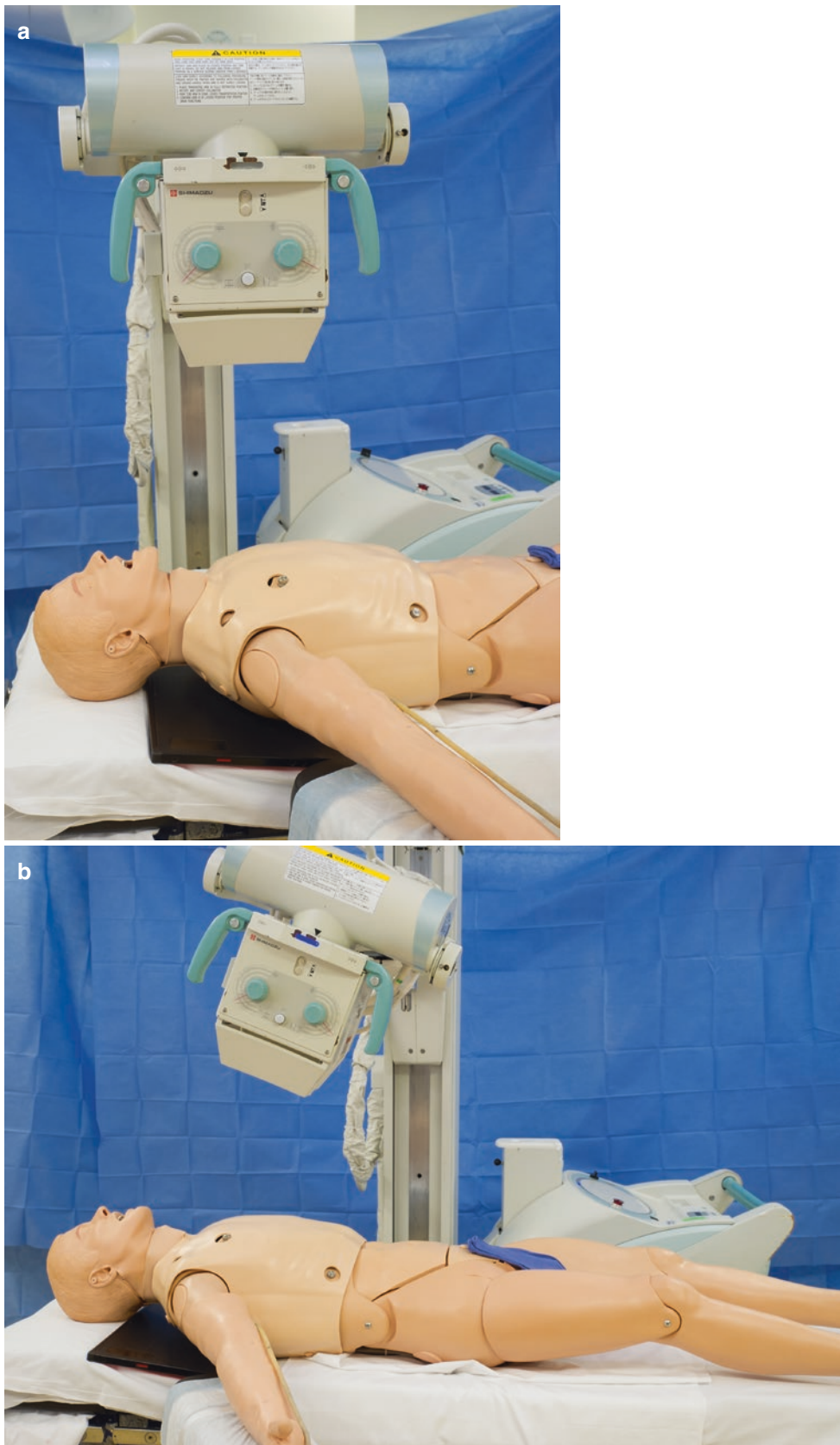


**Fig. 5.19** (a–c) Hand taken down from suspension and fingers painted





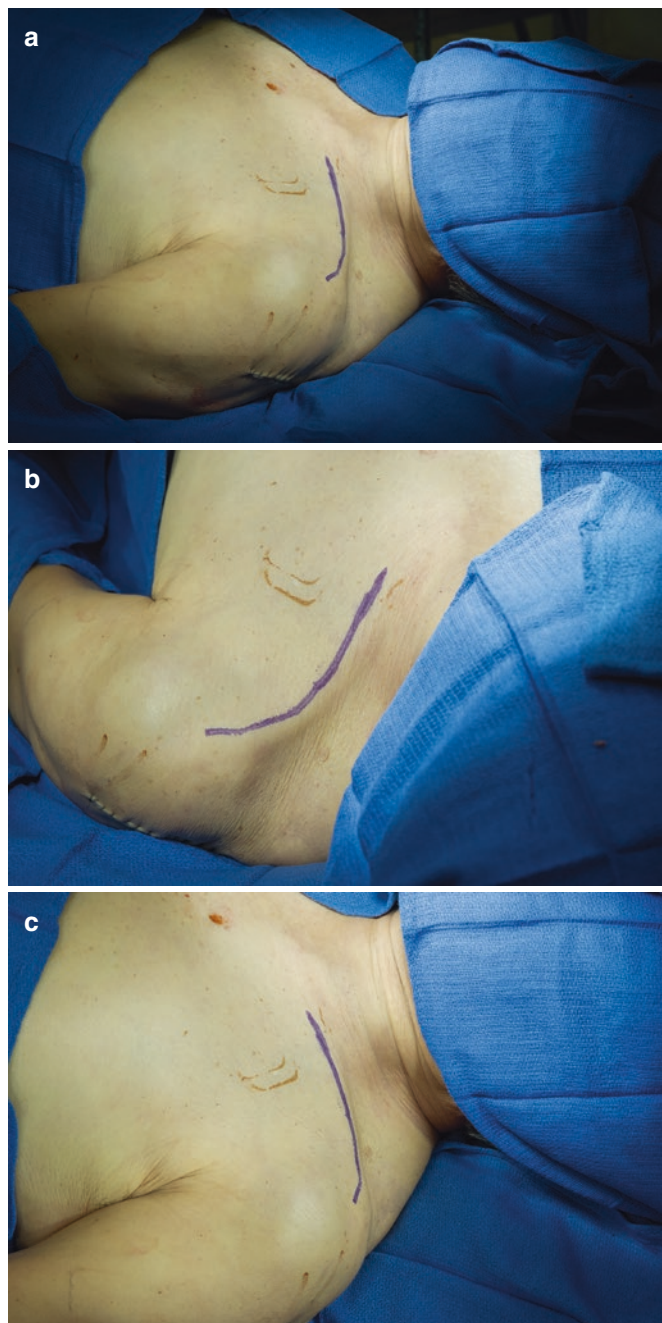
**Fig. 5.20** (a, b) Positioning, head upright, centered under lights



**Fig. 5.21** AP radiographs (a) and lordotic radiographs (b) in operating room with back table sterile

### 5.2.3 Incision that Preserves the Supraclavicular Nerves

The curvilinear incision is slightly inferior to the clavicle as opposed to being directly over the clavicle (Fig. 5.22).



**Fig. 5.22** A curvilinear incision inferior to clavicle, so the incision is not directly over the plate: lateral view (a), superior view (b), and distal view (c)

The platysma is divided. I do endeavor to preserve the supraclavicular nerves; generally, there are two or three (Fig. 5.23).



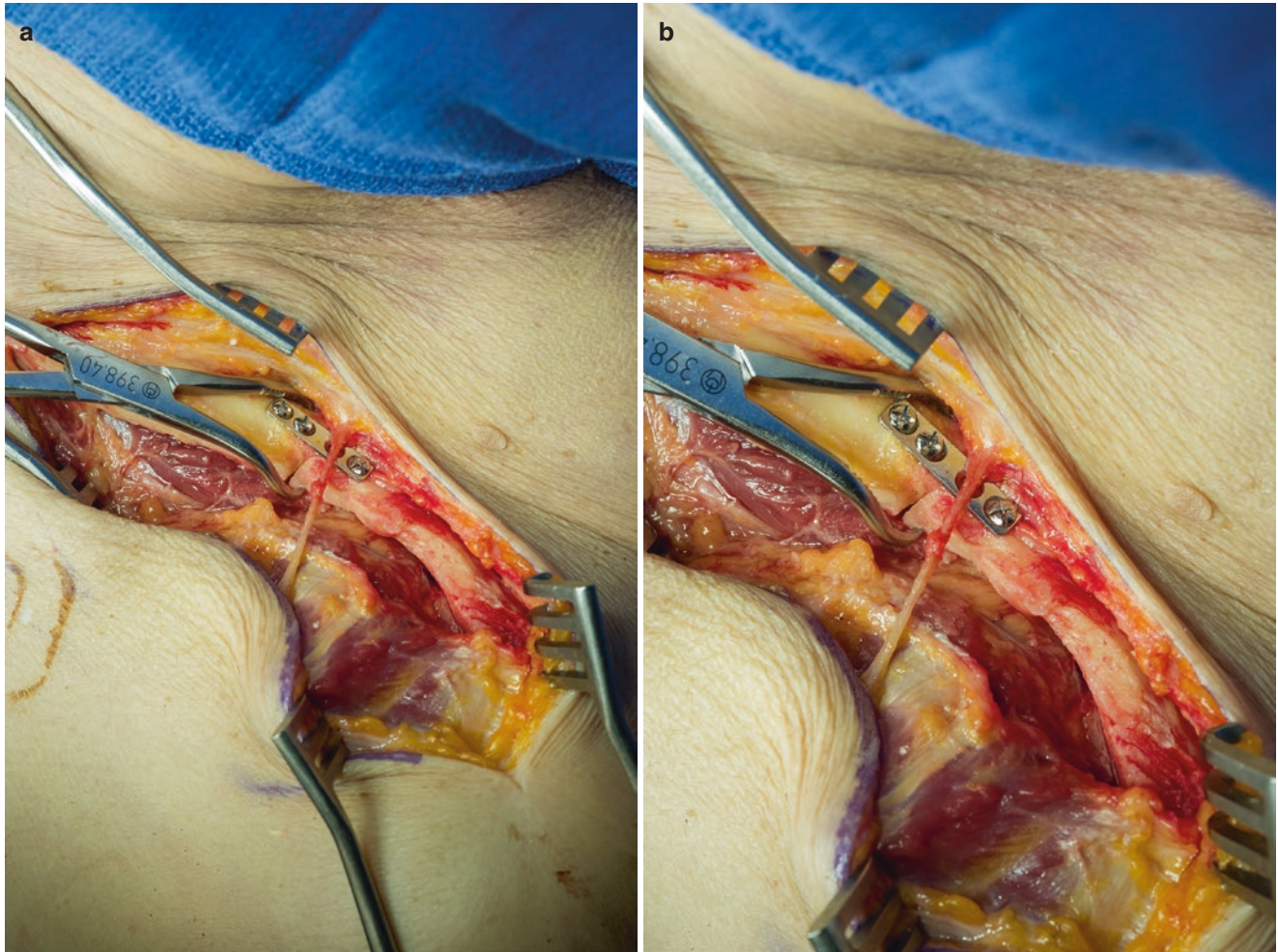
**Fig. 5.23** Exposure with supraclavicular nerve preserved

I endeavor to preserve these nerves, particularly in a woman, because of alteration of sensation in the superior aspect of the breast. If the plate is removed, it is very difficult to preserve these nerves during the plate removal because the nerves can look like little fibrotic scar bands and are difficult to isolate. The vessels that tend to run with these nerves, however, can help facilitate their identification, particularly during the initial surgical approach. With the nerves preserved, the clavicle is approached in a subperiosteal fashion, elevating the pectoralis major and the deltoid as far as needed for adequate control and fixation. The approach is performed through windows between the nerves.



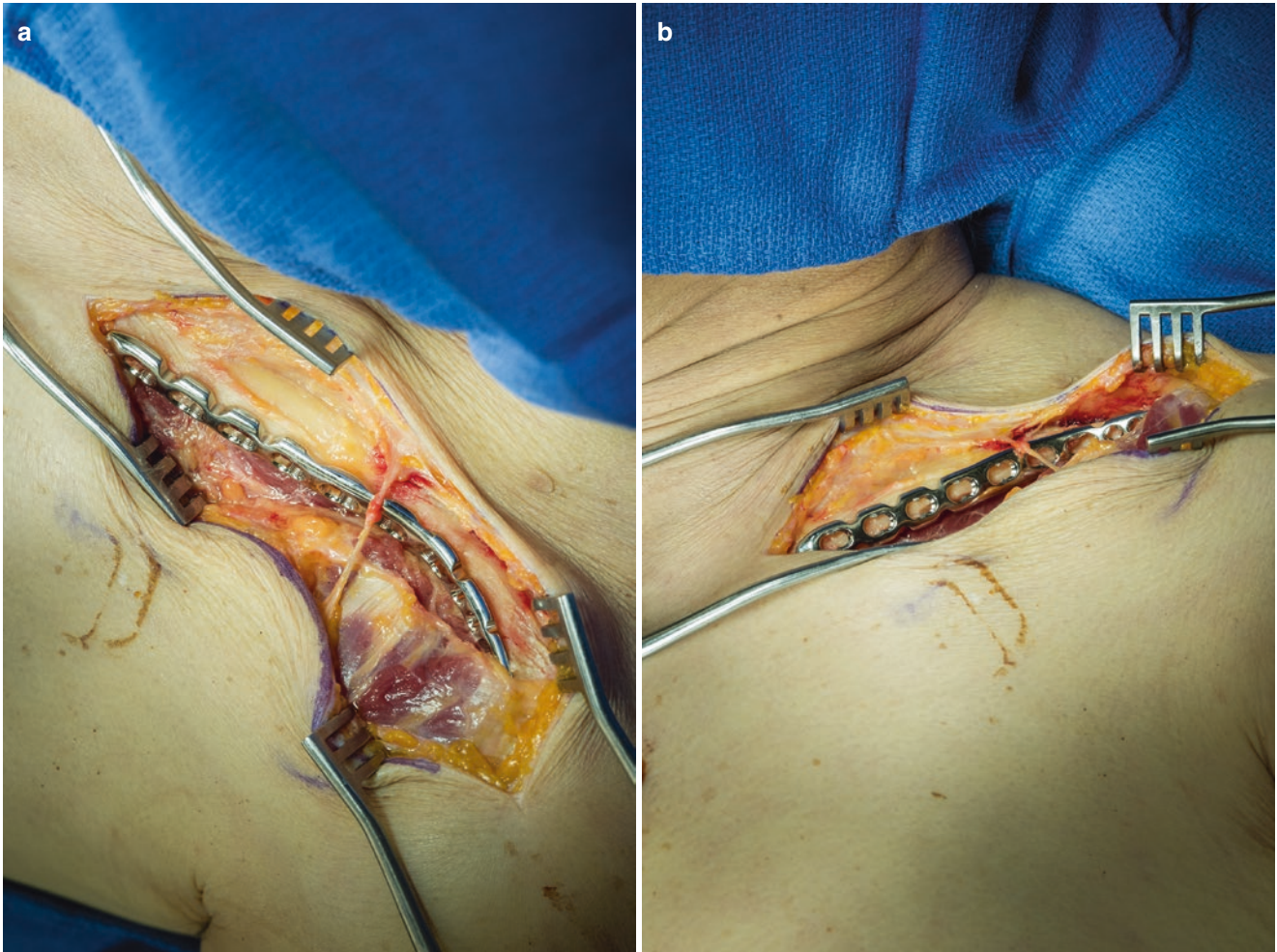
### 5.2.4 Fixing the Fracture

Once the incision has been made, the fracture is prepared. There is usually a butterfly or obliquity, which will be amenable to lag screw or mini-plate fixation (Fig. 5.24).



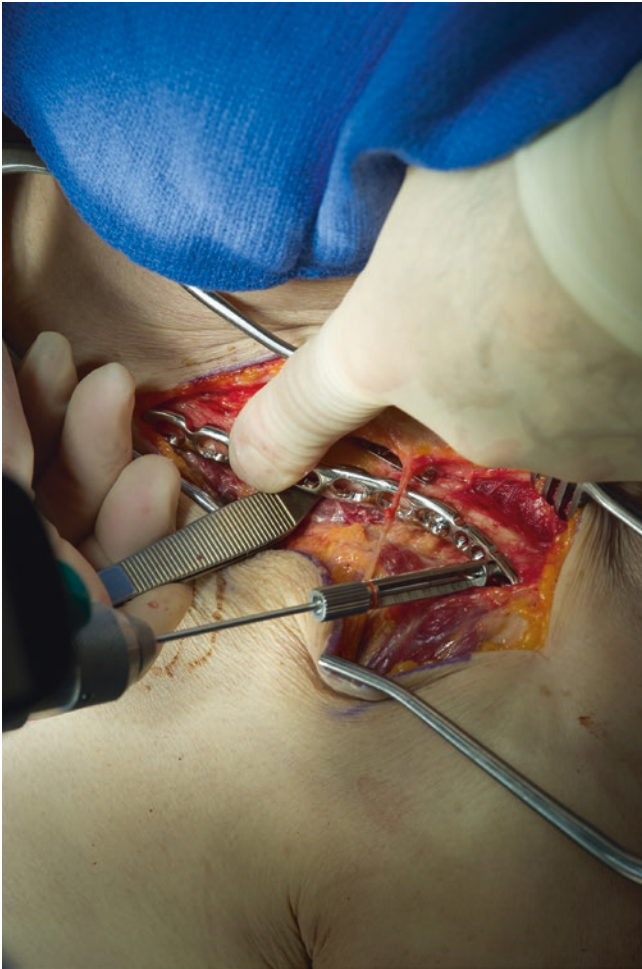
**Fig. 5.24** (a, b) Pectoralis major elevated from anterior aspect of clavicle; reduction with tenaculum and provisional reduction with four-hole, 2.0 DCP plate

I prefer to have four screws with eight cortices on either side of the fracture, but three screws have sufficed with more lateral fractures, where smaller locking screws have been effective (Figs. 5.25, 5.26, and 5.27).

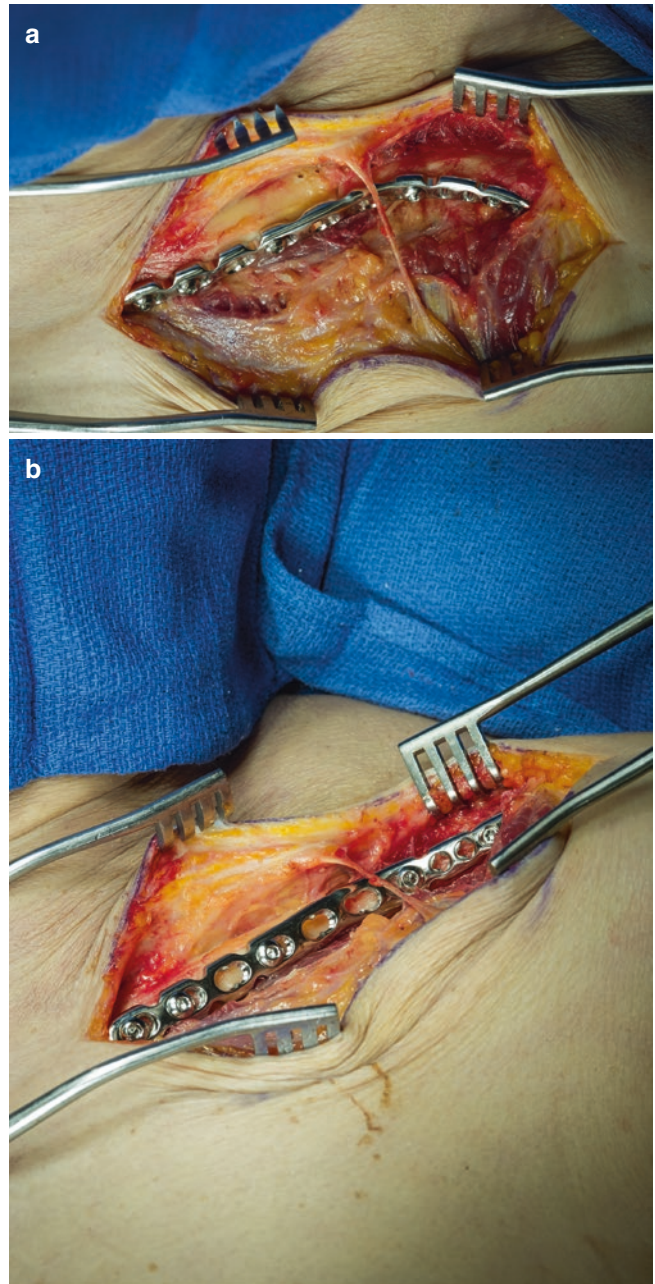


**Fig. 5.25** (a, b) Plate positioned for demonstration purposes, anteriorly preserving nerve





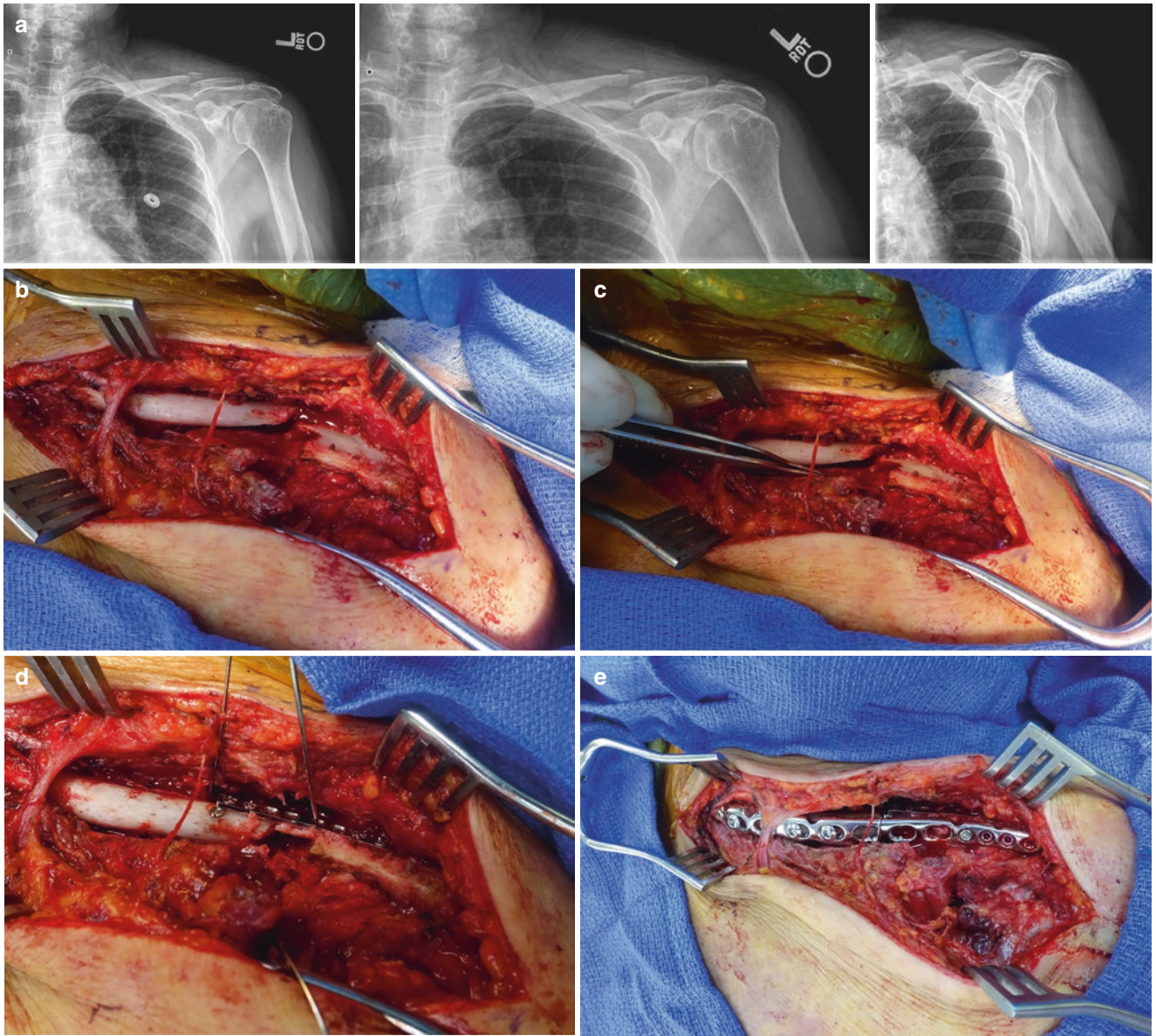
**Fig. 5.26** Plate aligned, over contouring with fixation, usually lateral first to ensure that the acromioclavicular (AC) joint isn't violated. The lateral locking screw is drilled in bicortical fashion so as not to glance off superior or inferior



**Fig. 5.27** (a, b) Fixation completed, with provisional plate removed. The provisional plate may be left in if needed for fragment stability

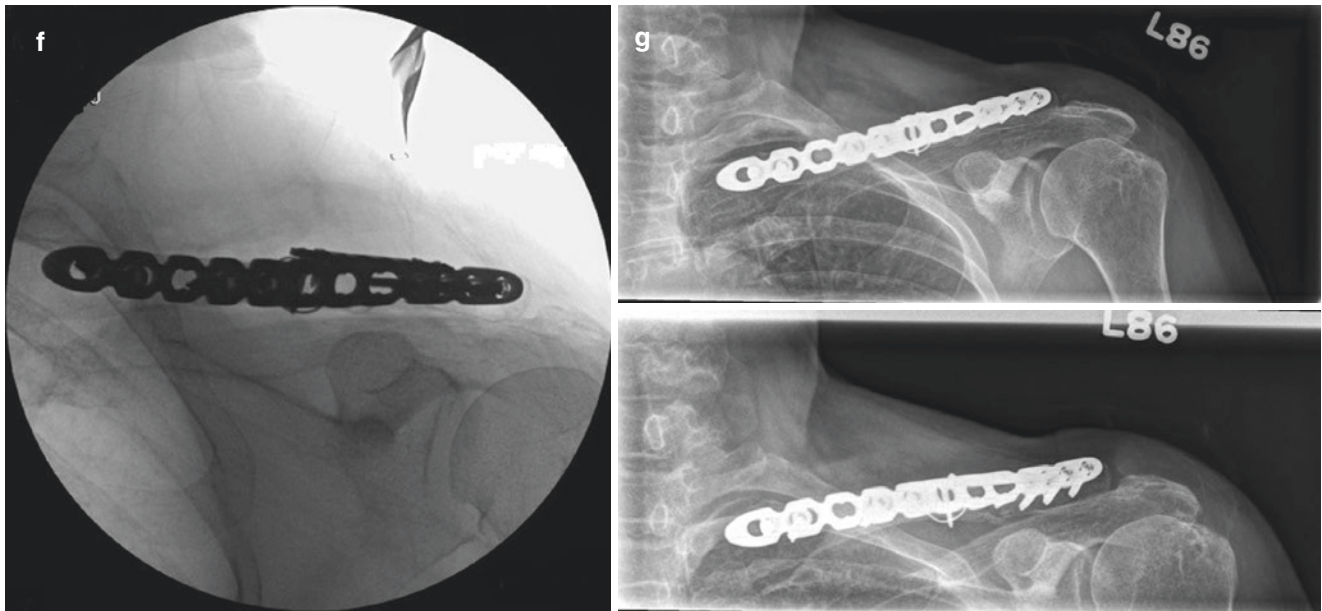


I do not routinely use an intraoperative C-arm unless the fracture is lateral and I want to make sure that the acromioclavicular or AC joint has not been violated (Fig. 5.28).



**Fig. 5.28** (a) Clinical example: Injury radiographs of left clavicle fracture. The patient requested ORIF. (b) Fracture exposure, preserving supraclavicular nerves. (c) Pickups pointing to inferior fragment with coracoclavicular ligament attachments. (d) Provisional fixation.

(e) Definitive fixation, including bone grafting. (f) Intraoperative C-arm shot of left AC joint. (g) Postoperative radiographs following anterior fixation



**Fig. 5.28** (continued)

Closure is performed in layers (in contradistinction to the arm, where I tend to close only the dermis and skin). The pectoralis and trapezius are approximated. The platysma is approximated, and then the skin is closed over a medium Hemovac® drain with a running subcuticular suture.

### 5.2.5 Rehabilitation Following Surgery

The range of motion is dictated by the patient's individual scenario and quality of bone. Generally, I prescribe use of a sling for a couple of weeks, but not much past this. I allow for range of motion, but encourage patients not to perform any strengthening or weight-bearing for about 6 weeks. On occasion, I have tried to allow a young athlete to return to his or her activities at 4–6 weeks, pending symptoms and radiographs. Hardware removal is predicated upon patient complaints and desires. One study reported that nearly 20% of patients requested hardware removal, with an overall reoperation rate of 24% [17].

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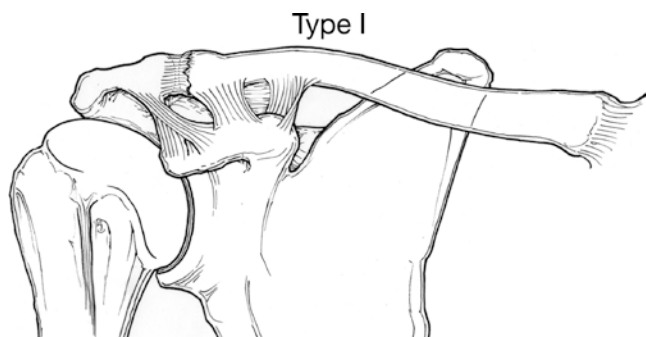
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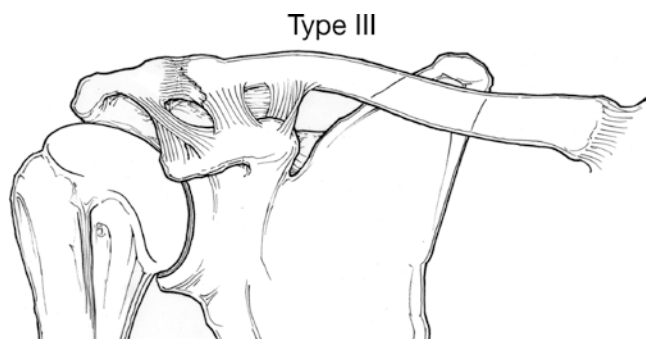
### 6.1 Types of Clavicle Fractures and Acromioclavicular (AC) Dislocations

Injuries to the lateral aspect of the clavicle may manifest as either a lateral clavicle fracture, with or without injury to the coracoclavicular (CC) ligament (conoid/trapezoid ligament),

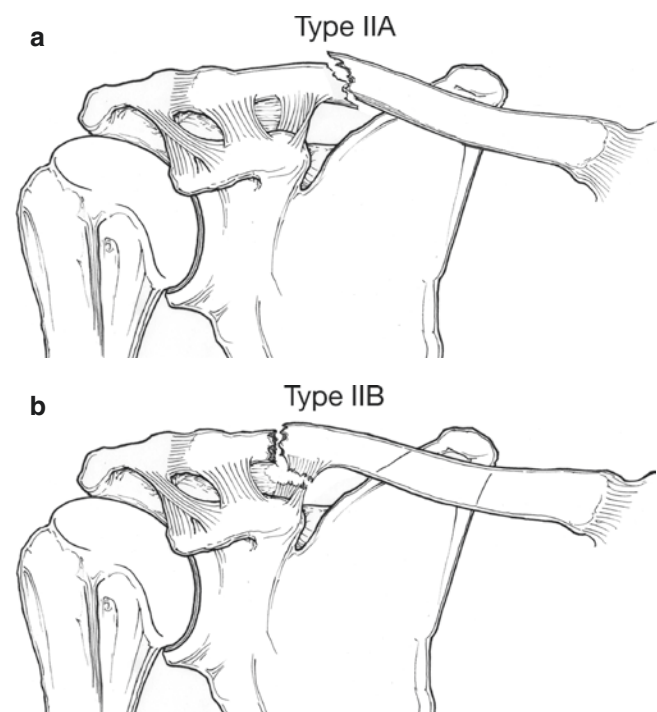
or as a pure AC separation. Fractures to the distal clavicle can occur medial to the CC ligaments or can be interligamentous or lateral to the CC ligaments, and intra-articular involvement may or may not occur. The three types of fracture to the distal clavicle are diagrammed in Figs. 6.1, 6.2, 6.3, and 6.4 [1–3].



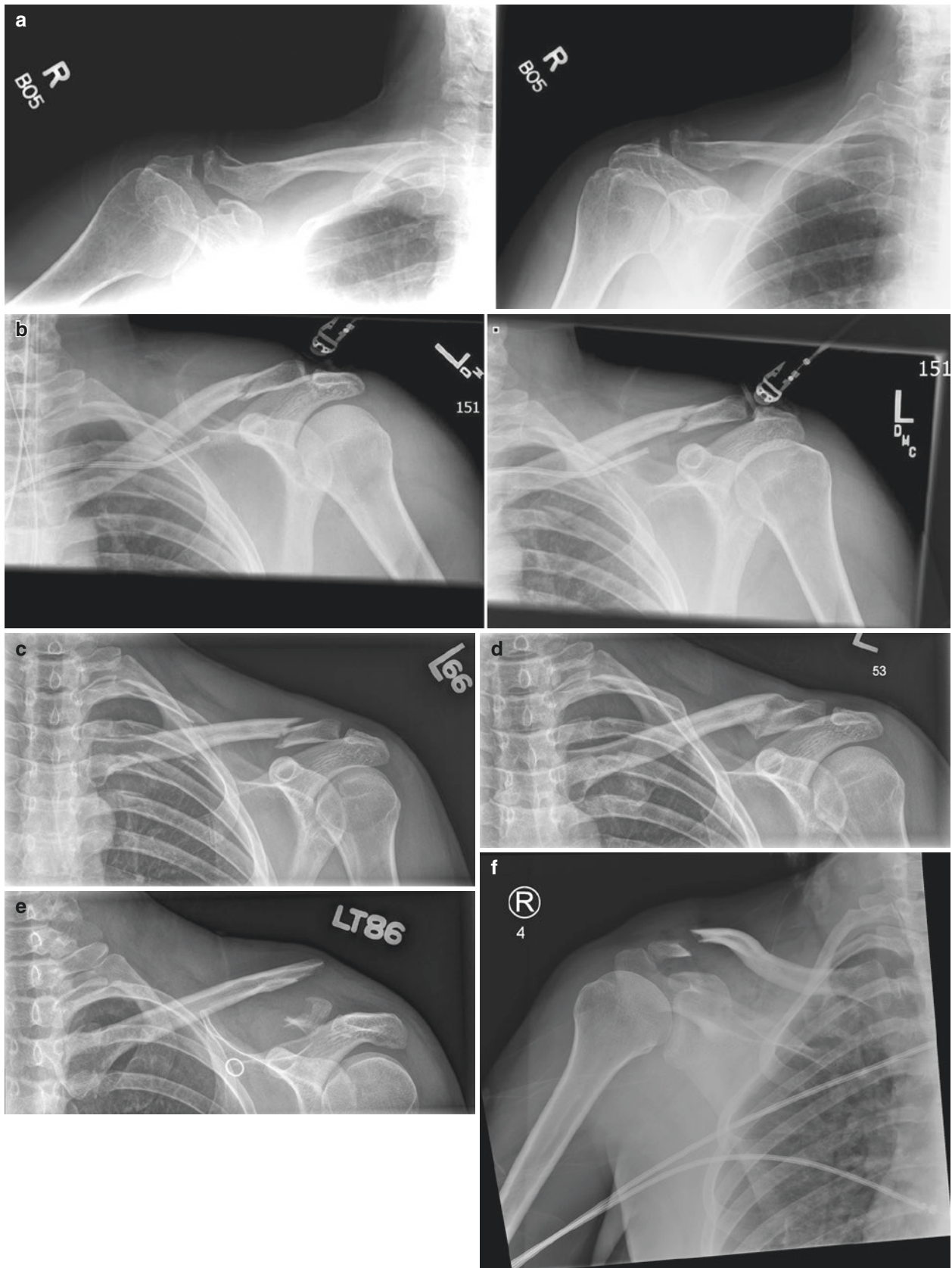
**Fig. 6.1** Distal clavicle fracture type I—extra-articular



**Fig. 6.3** Distal clavicle fracture type III—intra-articular



**Fig. 6.2** (a) Distal clavicle fracture type IIA—medial to coracoclavicular (CC) ligament. (b) Distal clavicle fracture type IIB—intraligamentous

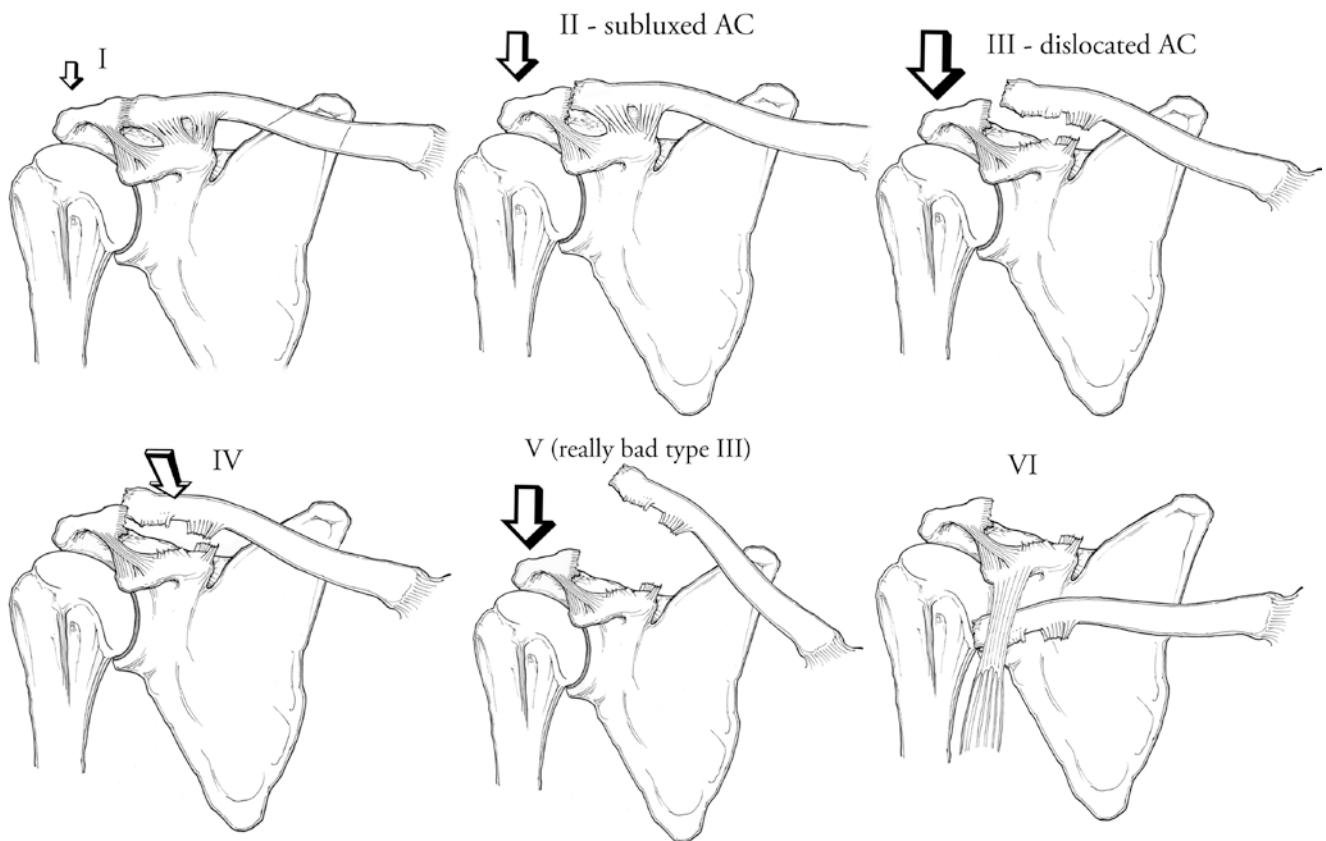


**Fig. 6.4** (a) Type I injury radiograph. (b) Type IIA injury radiograph. (c) Type IIA follow-up radiograph. (d) Type IIA discharge radiograph. (e) Type IIB injury radiograph. (f) Type IIB injury radiograph. (g) Type III injury radiograph. (h) Type III follow-up radiograph



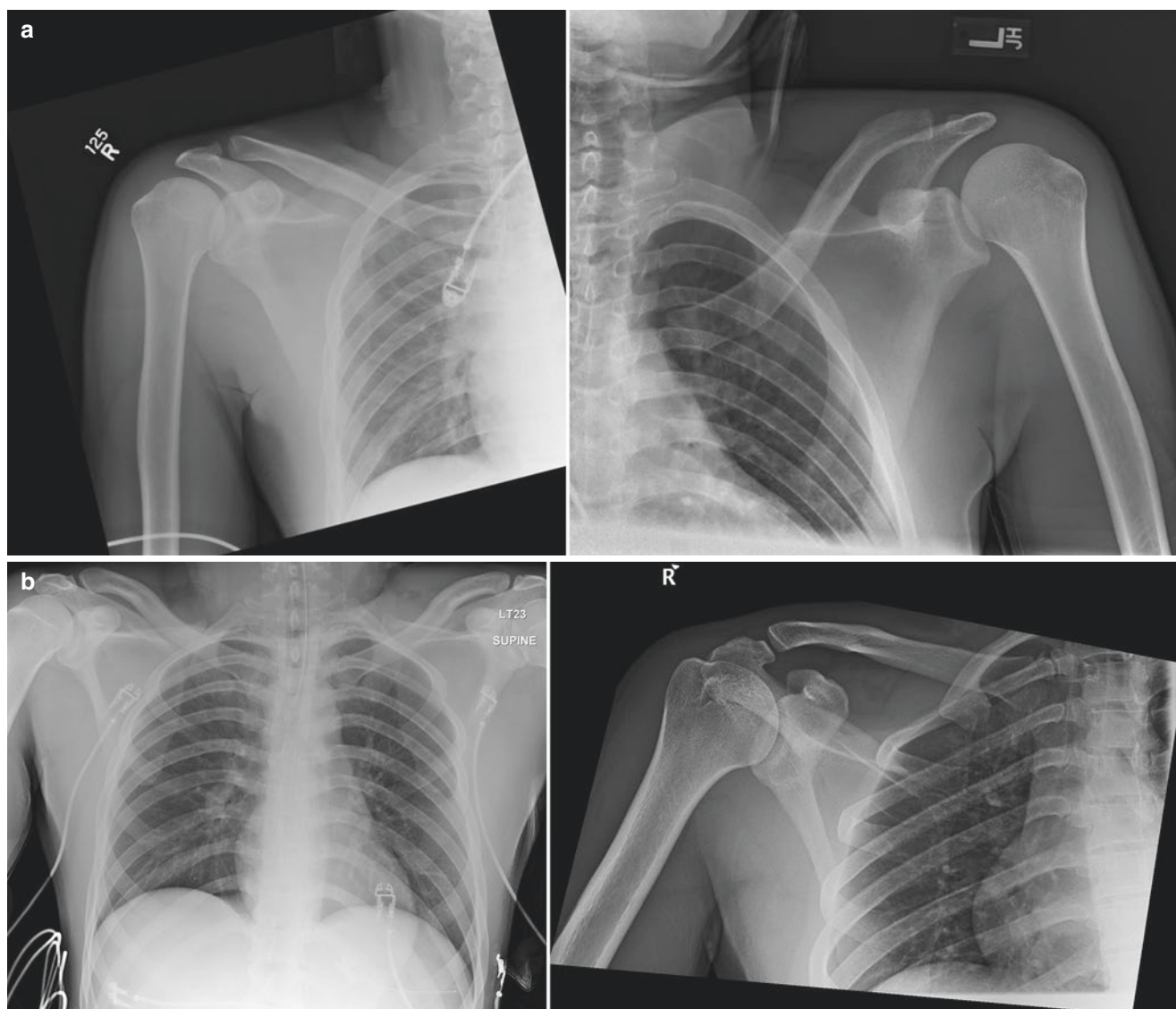
**Fig. 6.4** (continued)

AC joint separations and dislocations are classified into six types or grades (Figs. 6.5 and 6.6) [4, 5].



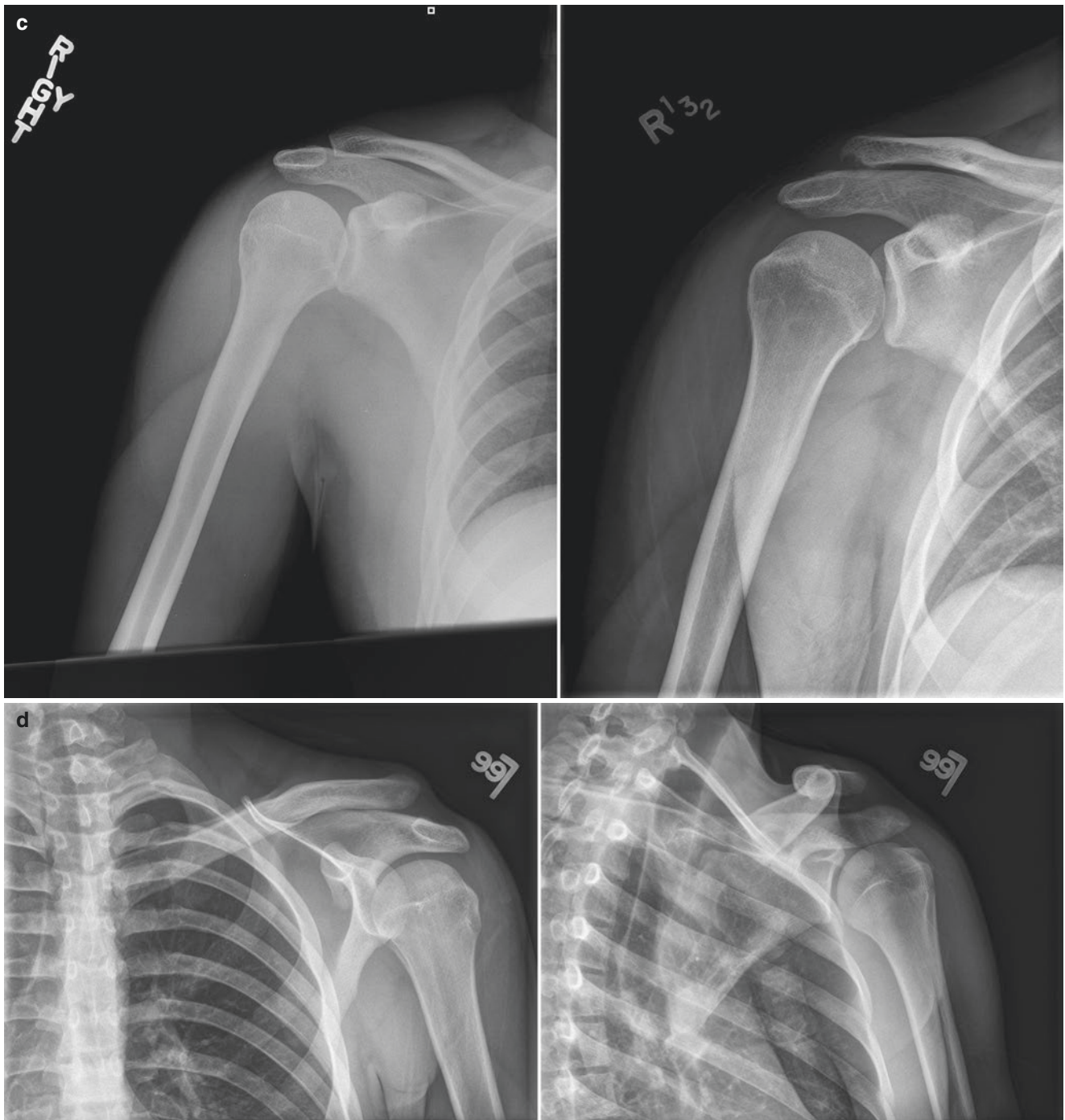
**Fig. 6.5** Acromioclavicular (AC) joint separations/dislocations



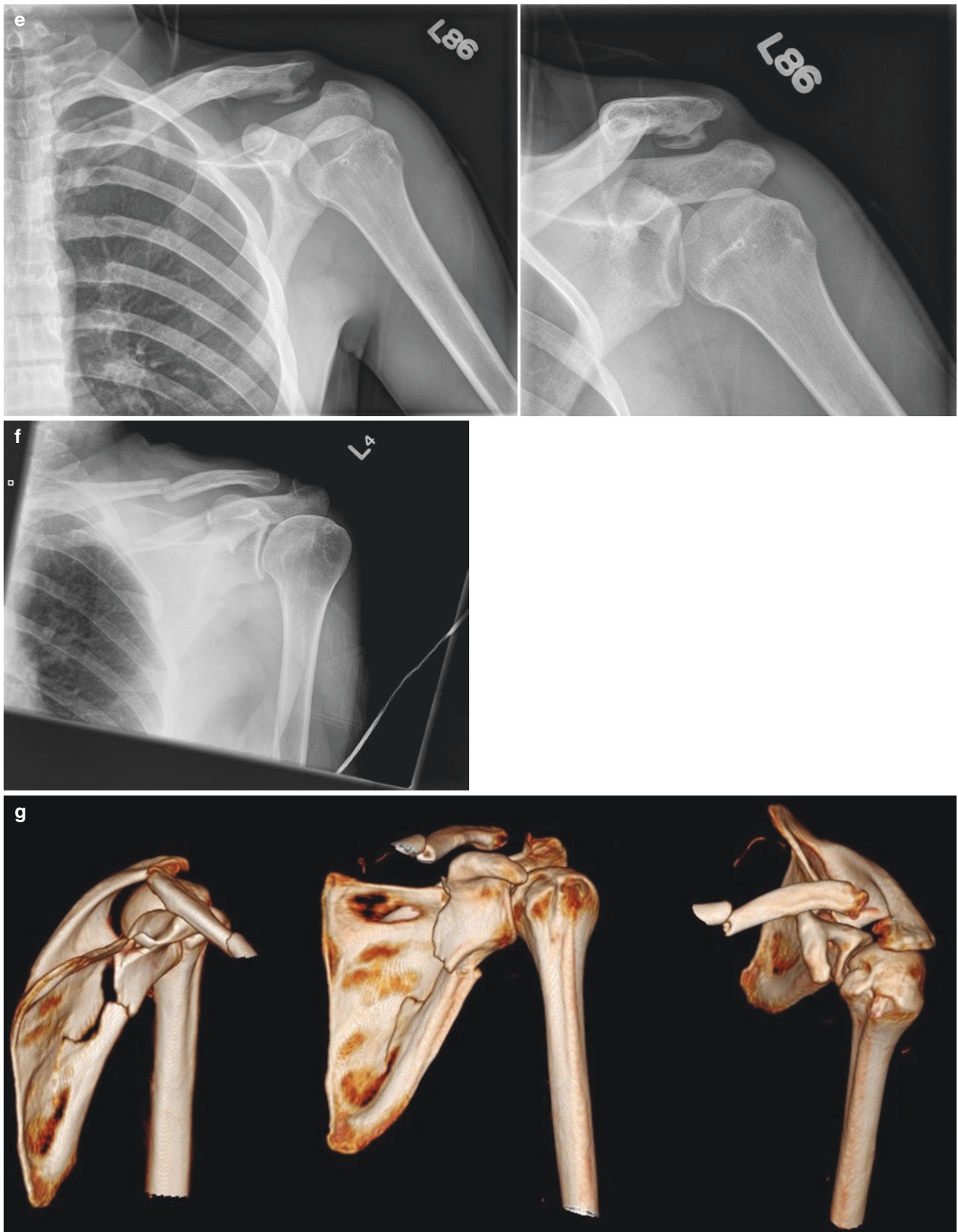


**Fig. 6.6** (a) Type I bilateral AC joint dislocations sprain, with pain on examination. (b) Type II AC separation. (c) Type II AC separation on presentation, which ultimately manifested as type III. (d) Type III AC dislocation. (e) Type III AC dislocation with follow-up radiographs demonstrating ossified, avulsed coracoclavicular (CC) ligament. (f) Type IV AC dislocation with associated mid-shaft clavicle fracture and

scapular neck fracture. (g) Three-dimensional (3-D) CT scan of patient demonstrating clavicle and scapula fractures and posterior AC dislocation. (h) Further displacement of clavicle prior to operative intervention. (i) Radiographs of left shoulder following open reduction and internal fixation (ORIF) with dual plates. (j) Type V AC joint dislocation

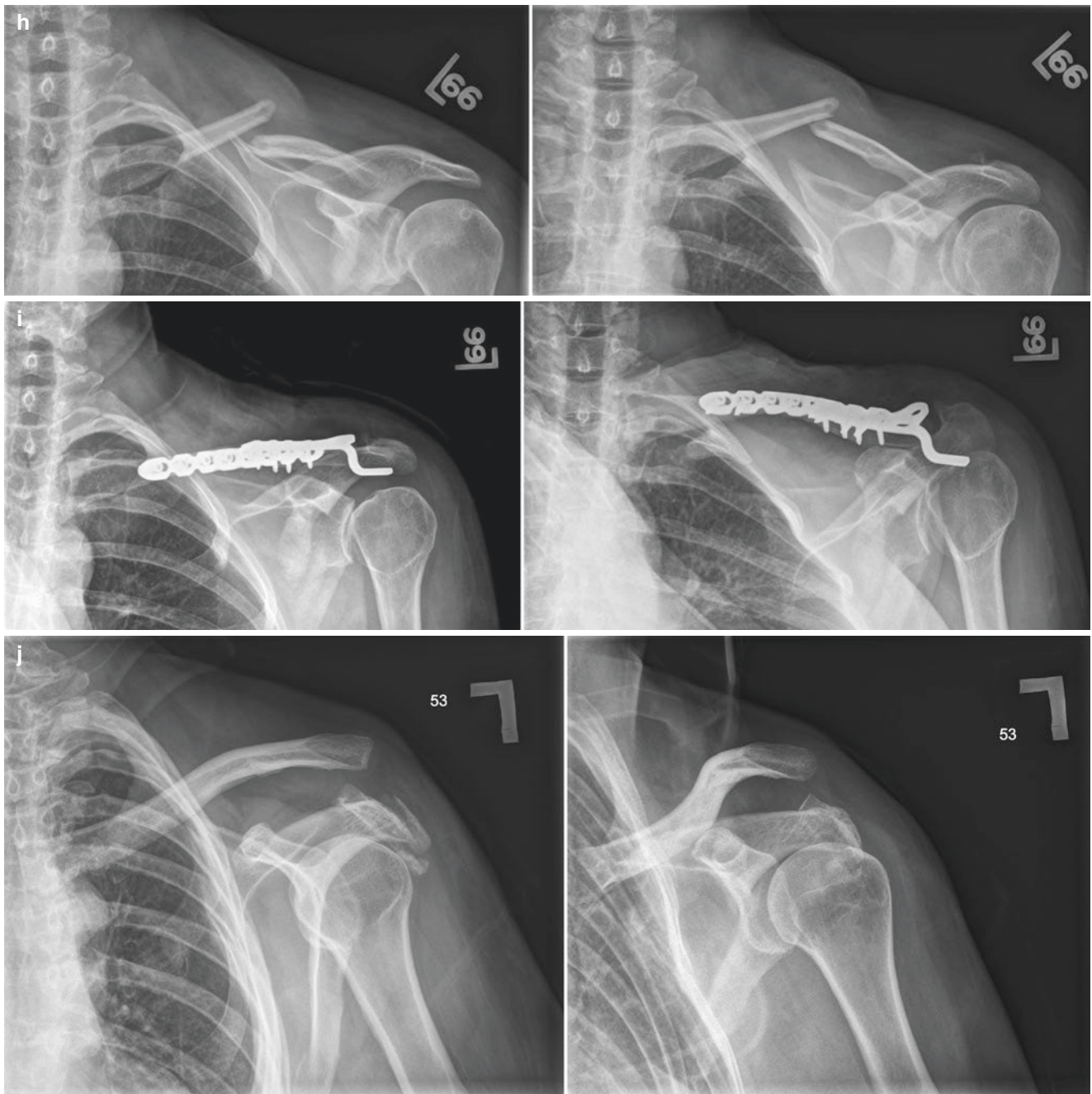


**Fig. 6.6** (continued)



**Fig. 6.6** (continued)





**Fig. 6.6** (continued)

I have no personal experience with the subcoracoid type VI dislocation [6].

## 6.2 Operative and Nonoperative Treatments

Controversy exists concerning appropriate treatment of lateral clavicle fractures and type III AC separations (Tables 6.1 and 6.2).

**Table 6.1** Summary of distal clavicle fracture studies

Author	Year	Patients	Results
Kona <i>et al.</i> [7]	1990	Follow-up of 19/35 pts with type II distal fractures after ORIF; 13 treated with Kirschner wires	9 unsatisfactory results 6 nonunion, 5 deep infections in pts treated with wires Recommendation: Do not use K-wires
Deafenbaugh <i>et al.</i> [8]	1990	10 pts with Neer type II distal fractures: non-operative treatment (average 14.3 mo follow-up)	7 healed 3 nonunion; no later surgery; occasional discomfort
Rokito <i>et al.</i> [9]	2002	30 type II distal clavicle fractures 14 op, 16 non-op	7 nonunions in non-op group No differences in pain, ROM, function, strength

*Non-op* non-operative, *Op* operative, *ORIF* open reduction internal fixation, *ROM* range of motion

**Table 6.2** Studies of acromioclavicular separation

Author	Year	Patients	Results
Galpin <i>et al.</i> [10]	1985	37 pts with grade III AC separation: 21 non-op (sling) 16 op, Bosworth screw and CC ligament repair	Earlier return to work in non-op group Similar functional strength results
Press <i>et al.</i> [11]	1997	26 pts with grade III AC separation 10 non-op 16 op	Non-op: Superior in time to return to work or athletics; less time of immobilization Op: Superior peak torque/work (but op group was younger, 31 vs 50 years) No difference in recovery of strength
Smith <i>et al.</i> [12]	2011	Meta-analysis, 6 studies of op vs non-op for grade III AC separation	Op: Better cosmesis No difference: strength, pain, throwing, osteoarthritis No advantage op vs non-op
Beitzel <i>et al.</i> [13]	2013	Literature review re: treatment of AC dislocation	Evidence lacking supporting treatment options

AC acromioclavicular, CC coracoclavicular, *Non-op* non-operative, *Op* operative

Distal clavicle fractures lateral to the coracoid can be successfully treated nonoperatively, although 33% of the nonoperatively treated fractures developed a nonunion in a meta-analysis review by Oh *et al.* [14]. AC separation types I and II are generally treated nonoperatively, whereas types IV, V, and VI are treated surgically. A number of studies show that AC joint dislocations, including type III, can be treated nonoperatively; the end results of closed treatment and open reduction are essentially equivalent.

A recent prospective study compared nonoperative to hook plate open reduction internal fixation (ORIF) of AC joint dislocation types III, IV, and V and found that the nonoperative group did better based on Disability of the Arm, Shoulder, and Hand (DASH) scores, but no difference was noted at 2 years [15]. Better cosmetic results were obtained by the operative group. Study results did not comment on CC ligament repair. The type of CC ligament repair may impact the ultimate clinical outcome, as put forth in studies examining anatomical repair technique [16–18].

## 6.3 Surgical Intervention and the Hook Plate

Whether the scenario requiring surgical intervention is an acute injury, chronic distal clavicle nonunion, or a painful AC separation, I prefer to use the hook plate, which I insert with the patient's understanding that removal is projected within 6–9 months.

The technique for hook plate insertion is similar to clavicle ORIF, with a few caveats. The patient is positioned on a Mayfield headrest that has been moved to the operative side.

The operative shoulder should be bumped, because there is need to gain access distally and posteriorly (Figs. 6.7, 6.8, 6.9, 6.10, 6.11, 6.12, 6.13, 6.14, 6.15, 6.16, 6.17, 6.18, 6.19, 6.20, 6.21, 6.22, 6.23, 6.24, 6.25, 6.26, and 6.27).



**Fig. 6.7** Positioning on Mayfield headrest with folded sheets behind shoulder



**Fig. 6.8** Positioning on Mayfield headrest with folded sheets behind shoulder



**Fig. 6.9** Kerlix® around head



**Fig. 6.10** Positioning on Mayfield headrest with folded sheets behind shoulder

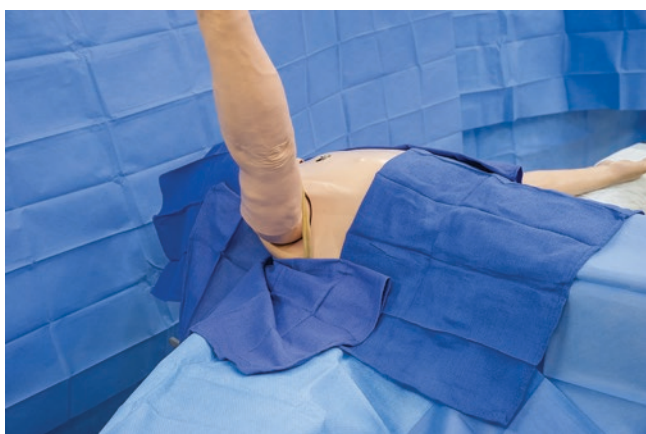




**Fig. 6.11** Body drape



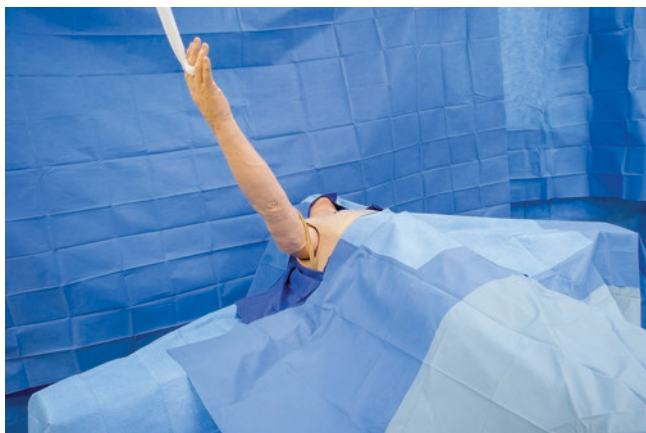
**Fig. 6.12** Three-fourths reinforced drape over arm board



**Fig. 6.13** Draping sequence: Four towels around surgical field



**Fig. 6.14** Draping sequence: Four towels around surgical field



**Fig. 6.15** Split sheet, tails down



**Fig. 6.16** Split sheet, tails down



**Fig. 6.17** Split sheet, tails up



**Fig. 6.18** Split sheet, tails up



**Fig. 6.19** Ioban™ around perimeter



**Fig. 6.21** Ioban™ around perimeter



**Fig. 6.20** Ioban™ around perimeter

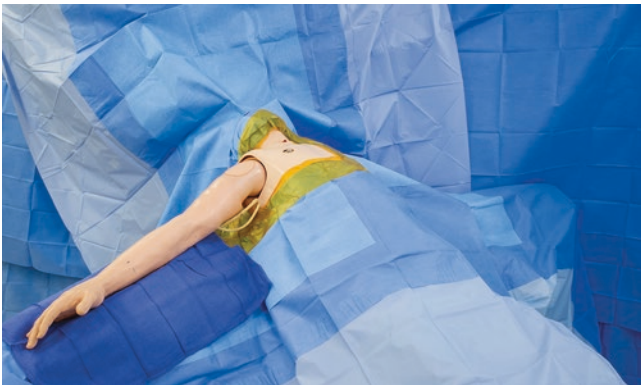




**Fig. 6.22** Fingers released and painted



**Fig. 6.23** Fingers released and painted



**Fig. 6.24** Anesthesia drape in place



**Fig. 6.25** Anesthesia drape in place



**Fig. 6.26** Postoperative anterior/posterior (AP) radiographs



**Fig. 6.27** Postoperative lordotic radiograph



The incision is similar to the clavicle approach inferiorly, but it then sweeps posteriorly, ending lateral to the acromion (Figs. 6.28 and 6.29).

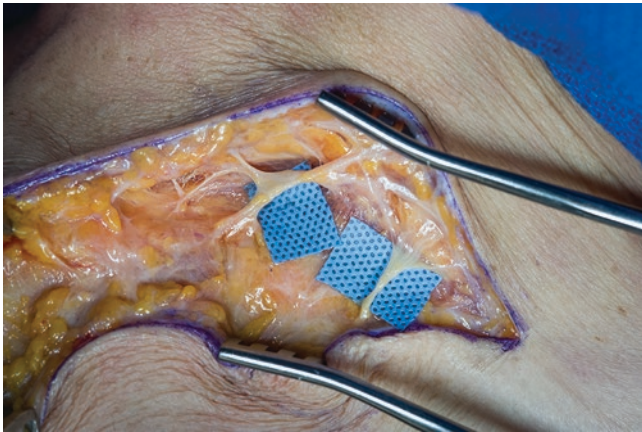


**Fig. 6.28** Incision extended laterally

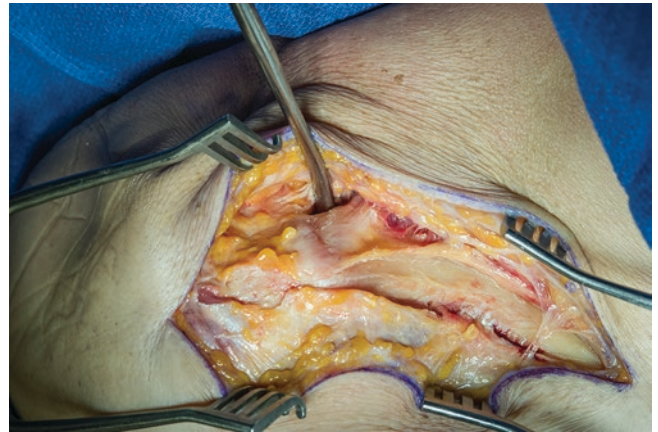


**Fig. 6.29** Incision extended laterally

The incision is performed with preservation of the supraclavicular nerves as much as possible (Fig. 6.30).



**Fig. 6.30** Supraclavicular nerves

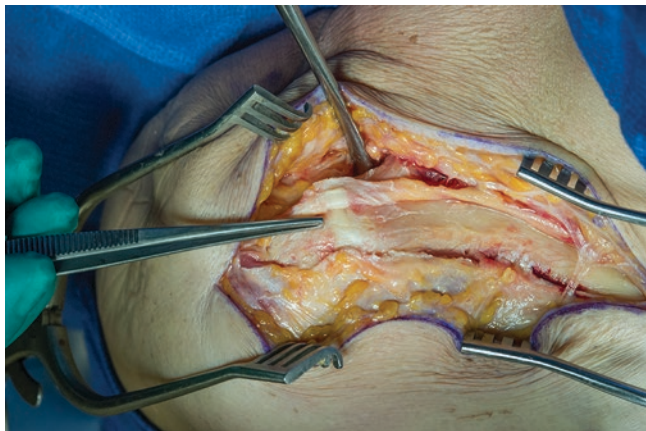


**Fig. 6.31** Position for blade placement of hook plate

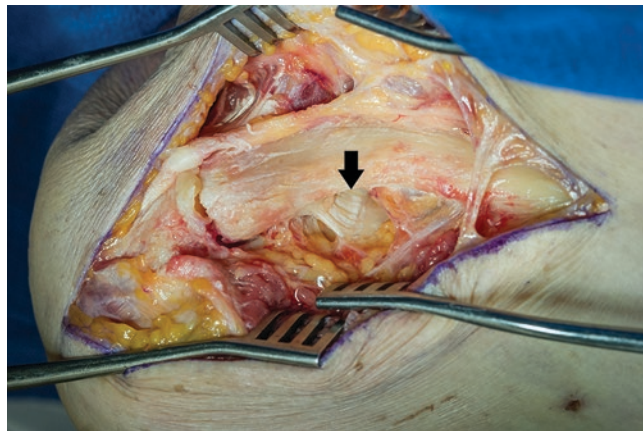
The reason for the posterior preparation is that it is important to feel the divot between the scapular spine, acromion, and lateral clavicle (Fig. 6.31).

The interval between the trapezius and the pectoralis major is developed subperiosteally. The avulsed AC liga-

ments are visualized laterally; they are routinely found to have been torn off of the clavicle (Figs. 6.32 and 6.33).

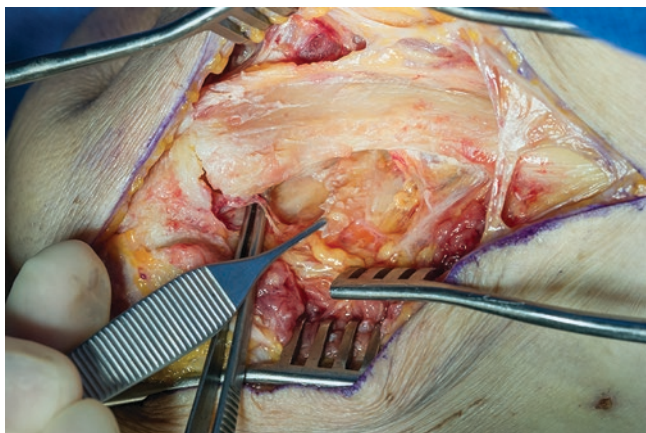


**Fig. 6.32** Pickups pointing to AC ligaments



**Fig. 6.33** AC joint ligaments divided, coracoclavicular (CC) ligaments intact (*arrow*)

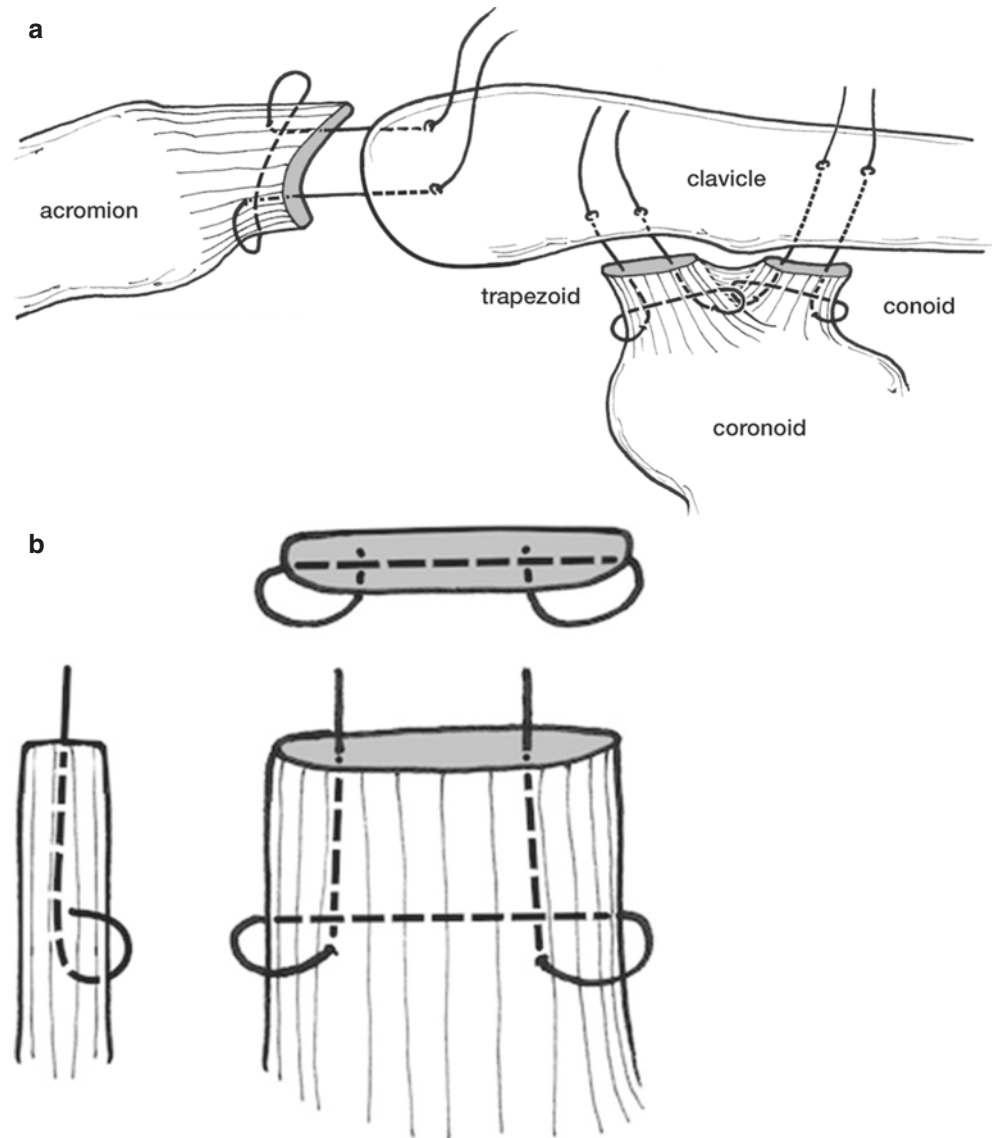
In an acute case, the CC ligaments usually are in confluence with the periosteum stripped off of the undersurface of the clavicle just superior to the coracoid (Fig. 6.34).



**Fig. 6.34** CC ligaments in pickups (forceps)

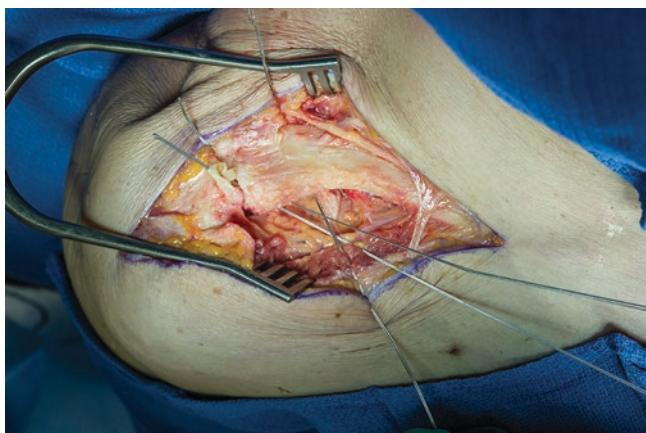
I repair the ligaments through 2.5-mm drill holes, using either #0 or #1 Ethibond® sutures placed using a locking, grasping pass (Fig. 6.35).

**Fig. 6.35** (a) Suture placement for ligament repair.  
(b) Suture placement using a locking, grasping pass

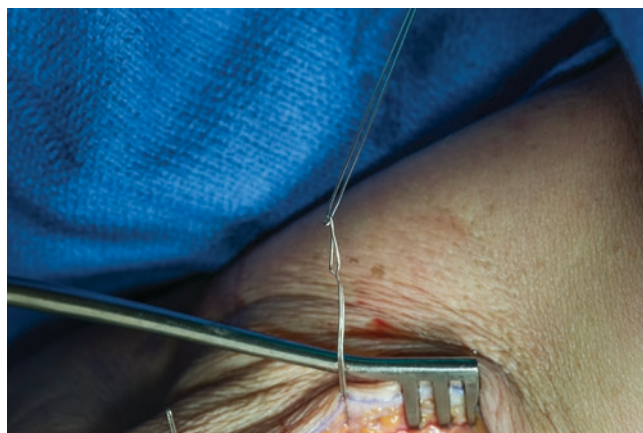




The sutures are passed through the bone using 24-gauge looped wire (Figs. 6.36, 6.37, and 6.38).

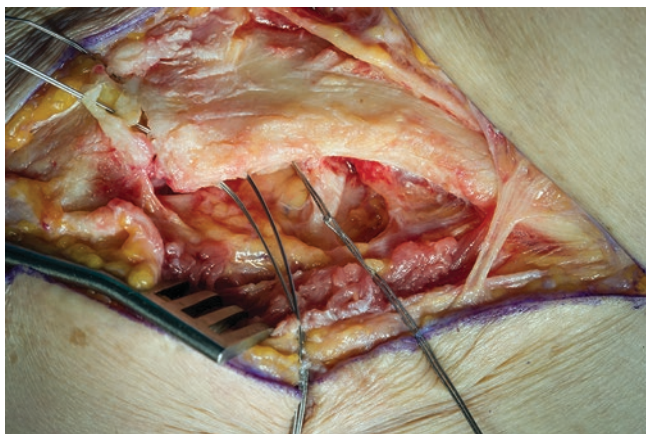


**Fig. 6.36** Wire passage using 24-gauge wire; two wires are used to gain proper suture passage. Finding posterior holes first can be difficult when passing posterior to anterior

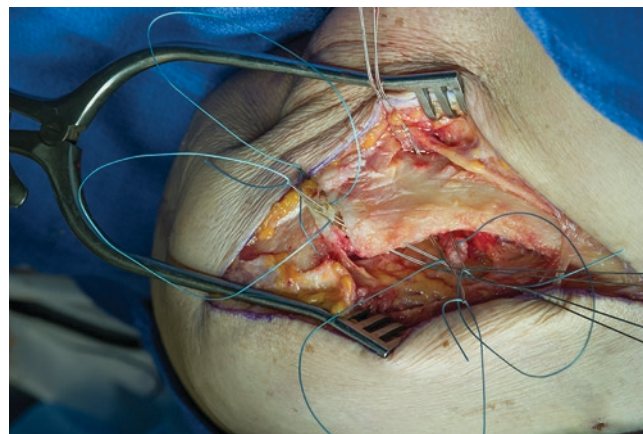


**Fig. 6.37** After passing wire anterior to posterior, a second wire is passed through the first loop and then pulled anteriorly

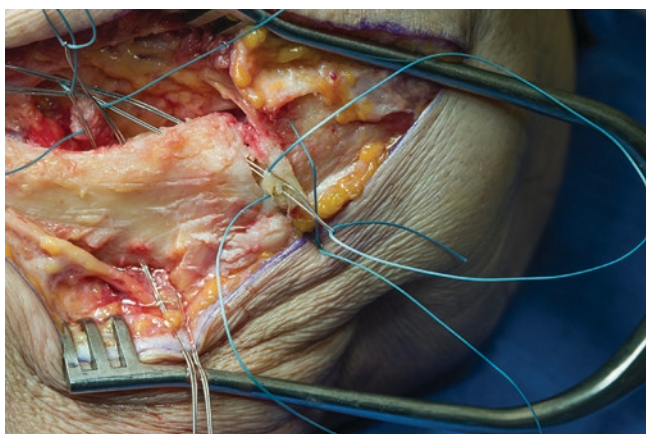
The sutures are placed prior to the AC joint or distal clavicle fracture reduction (Figs. 6.39, 6.40, and 6.41).



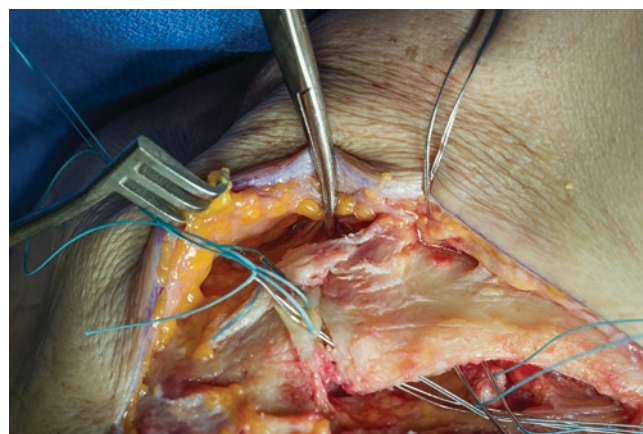
**Fig. 6.38** Wires are now positioned to allow sutures to be passed from anterior to posterior



**Fig. 6.39** Sutures fed through wire loops



**Fig. 6.40** Sutures fed through wire loops



**Fig. 6.41** Sutures fed through wire loops



The reduction is then performed. The sutures are tied after fixation is completed. The hook is placed posterior to the clavicle and requires insertion in a vertical fashion,

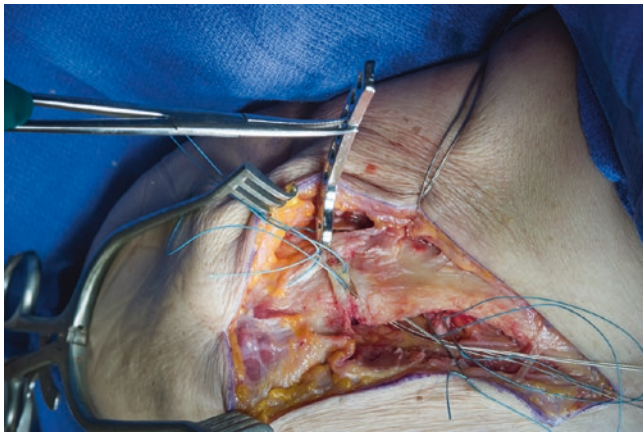
delivering the plate to the clavicle while the arm is pushed superior/cephalad to assist in the reduction of the AC joint or distal clavicle (Figs. 6.42, 6.43, 6.44, and 6.45).



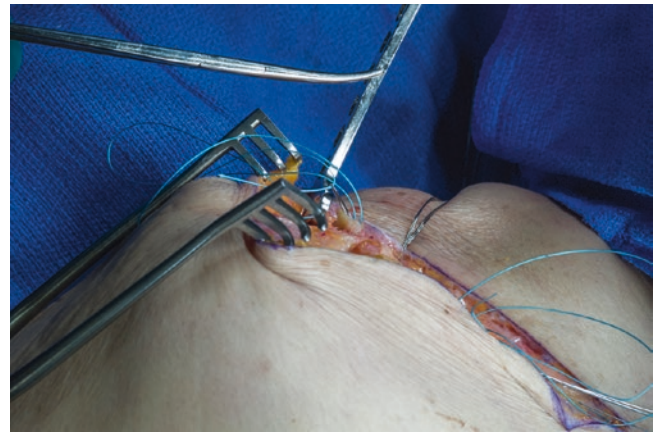
**Fig. 6.42** Hook plate



**Fig. 6.43** Hook plate



**Fig. 6.44** Vertically oriented hook plate

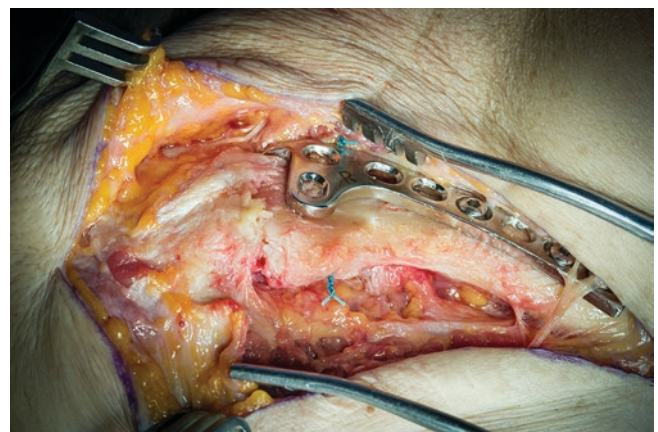


**Fig. 6.45** Vertically oriented hook plate

Depending on the force required, frequently I use a series of Kochers, lion jaws, lobster claws, and occasionally cerclage wires, followed by sequential screw insertion. After fixation is completed, the sutures are tied (Figs. 6.46 and 6.47).

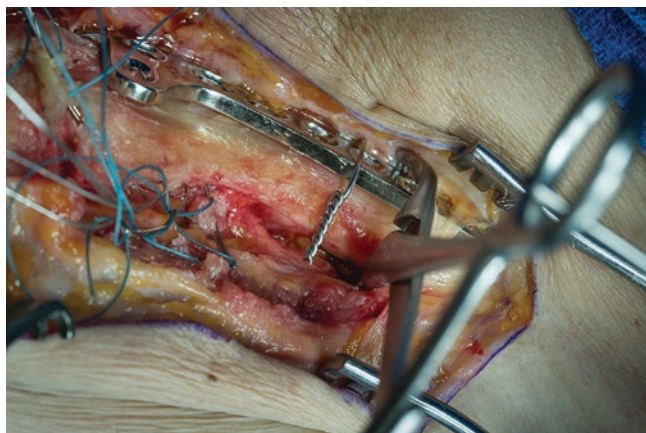


**Fig. 6.46** Fixation completed, sutures tensioned



**Fig. 6.47** Fixation completed, sutures tied

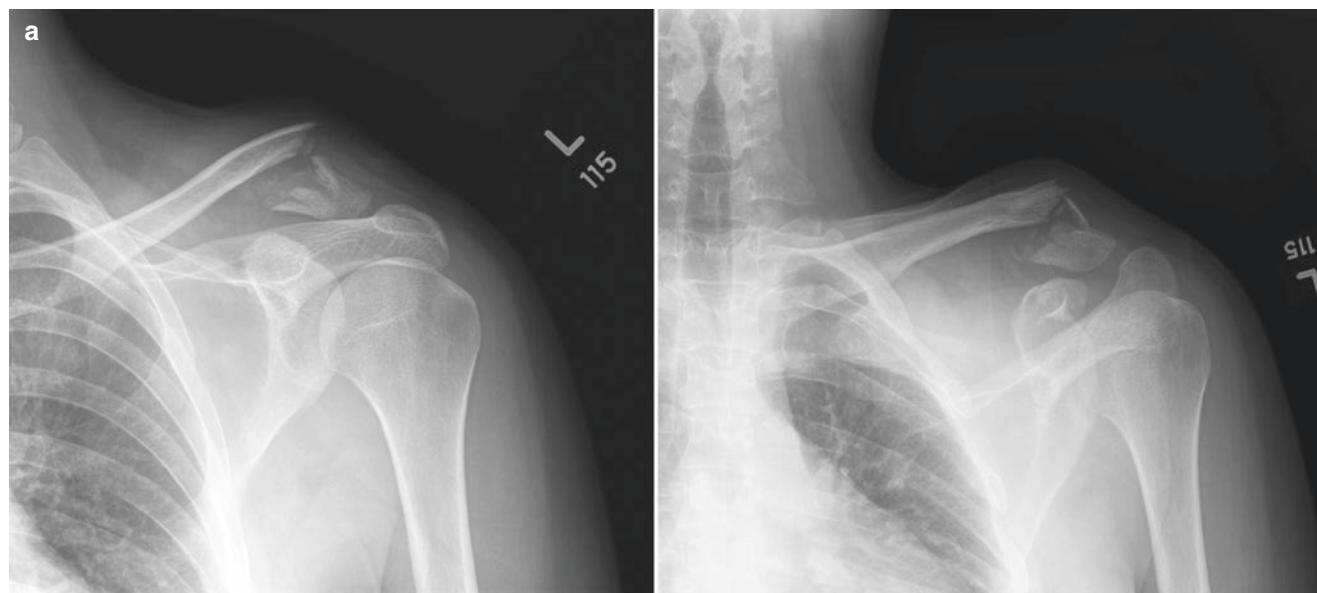
One should not try to deliver the plate to the clavicle using screws only, as screws tend to strip out. A slight over-reduction (*ie*, distal clavicle under the surface slightly past the undersurface of the acromion) is not an issue. Occasionally I will use a cerclage wire as reinforcement because the force can be rather great when trying to perform the reduction, particularly in a patient with a subacute or chronic injury (Fig. 6.48).



**Fig. 6.48** Cerclage wire used to reinforce or assist in reduction

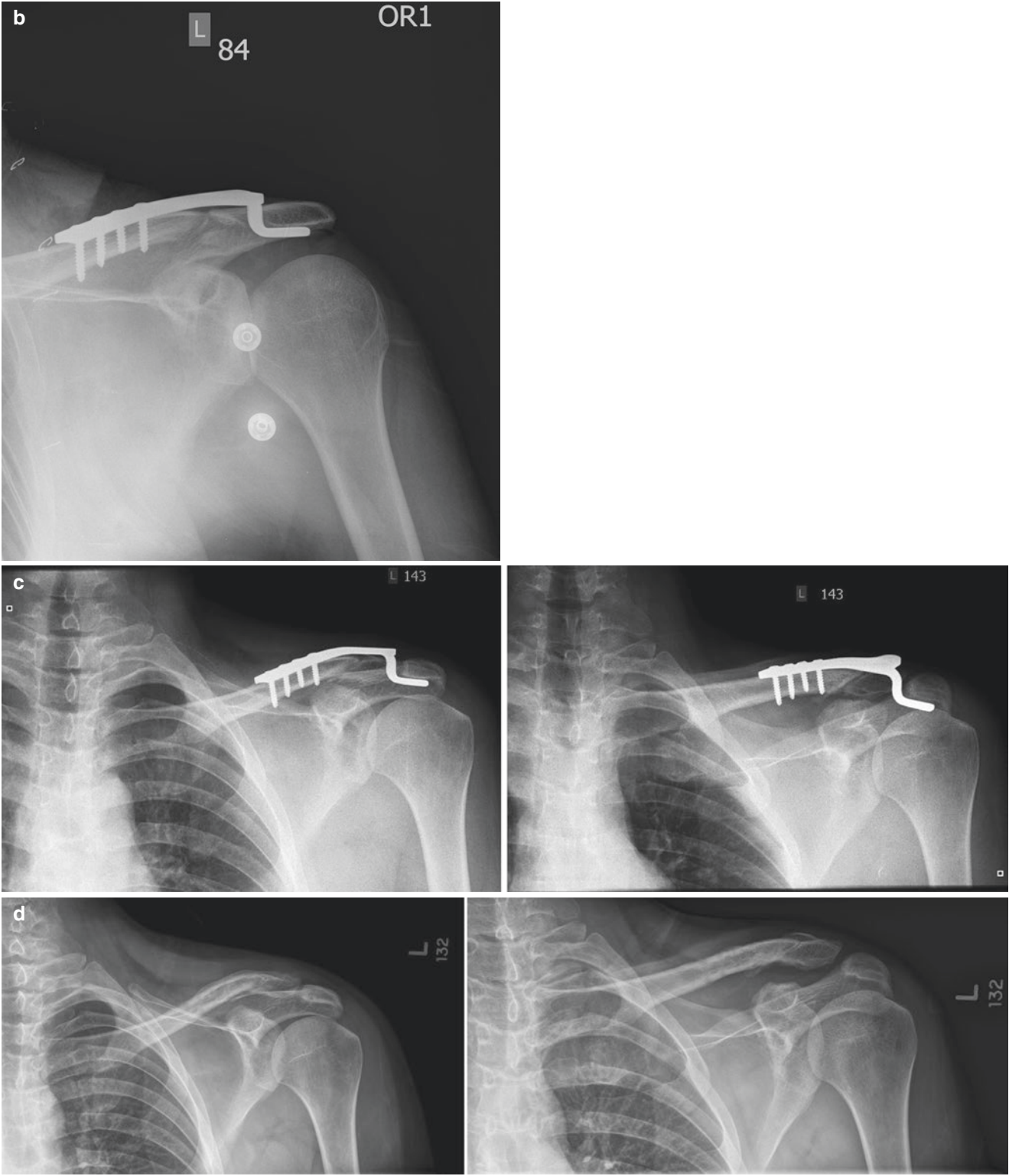
## 6.4 Patient Instructions

Depending on the injury, I prescribe the use of a sling for 2 weeks, then active assisted range of motion for 2 weeks, followed by unrestricted range of motion for 2 weeks, and then strengthening at 6 weeks. Hook plate removal is usually performed 6–9 months after insertion (Fig. 6.49), but patients who have declined hook removal for various reasons, including work or insurance issues, have done so without apparent negative consequences (Figs. 6.50, 6.51, 6.52, 6.53, 6.54, 6.55, 6.56, and 6.57).

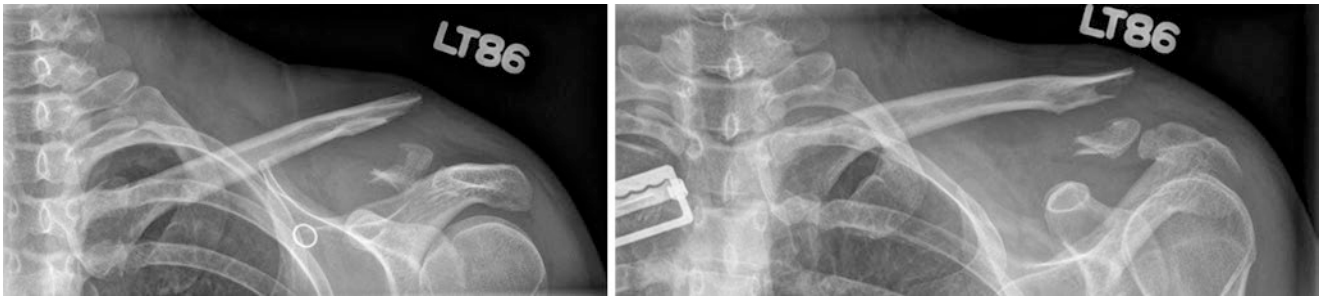


**Fig. 6.49** (a) Injury radiographs of type IIB distal clavicle fracture; the patient requested surgery. (b) Intraoperative radiographs. Notice no fixation of the distal clavicle. (c) Radiographs before hardware removal. (d) Radiographs following hardware removal

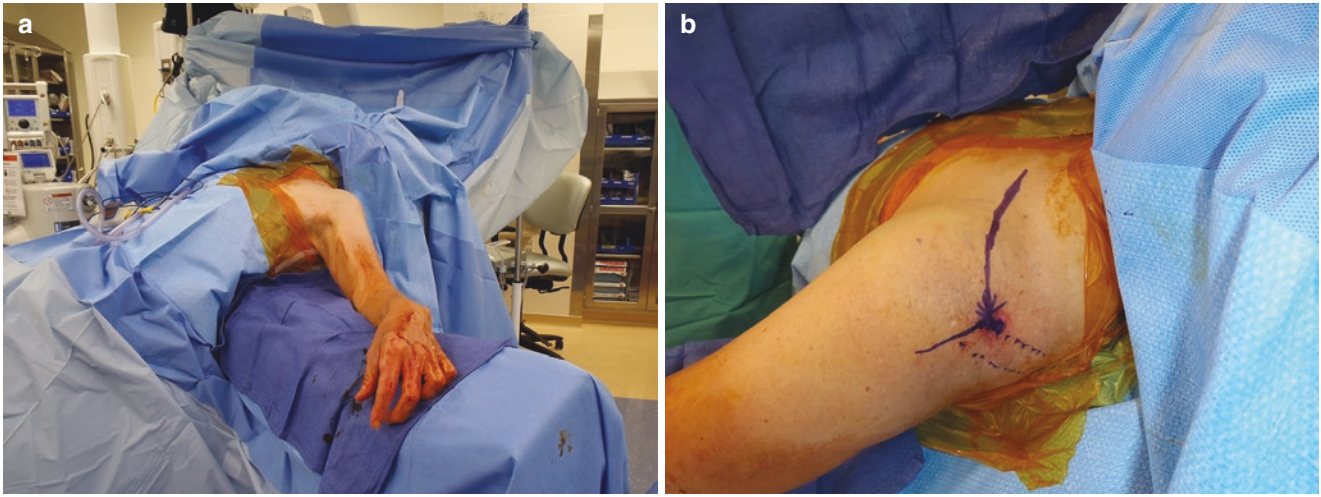




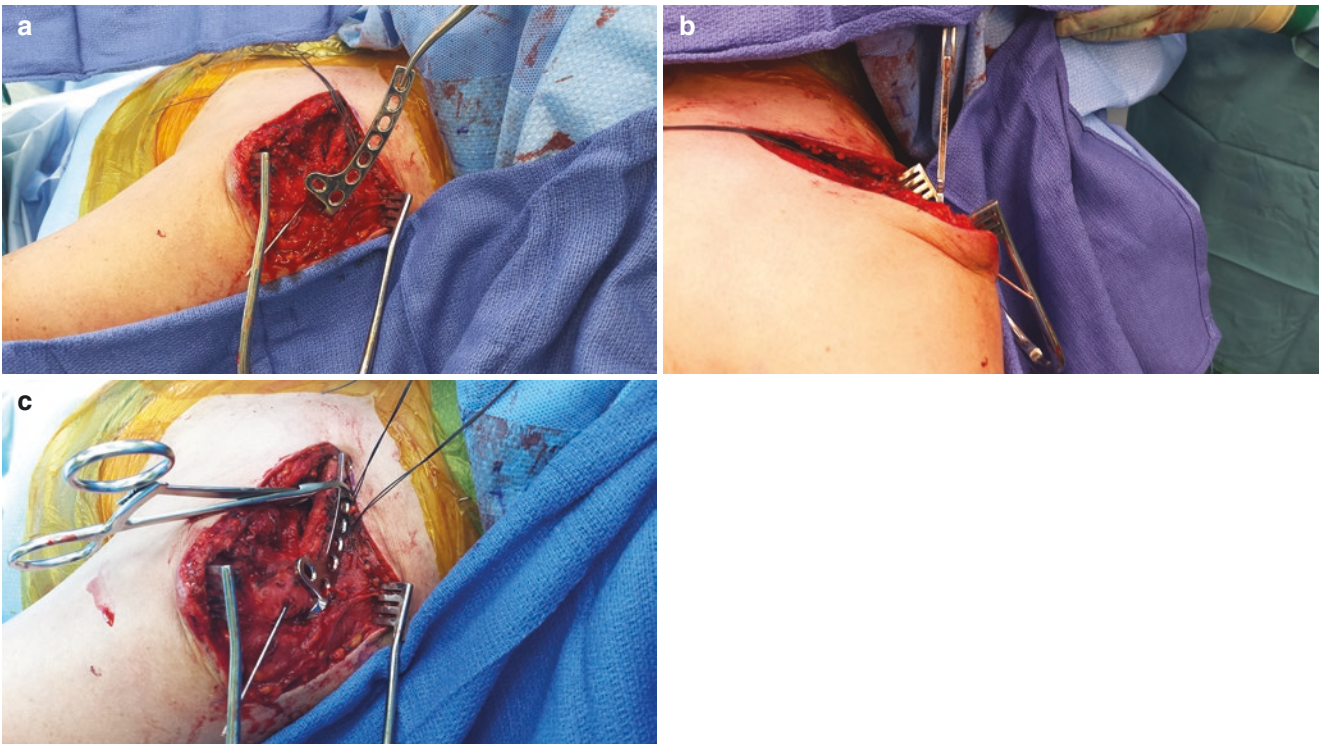
**Fig. 6.49** (continued)



**Fig. 6.50** Clinical example of type IIB distal clavicle ORIF: injury radiographs

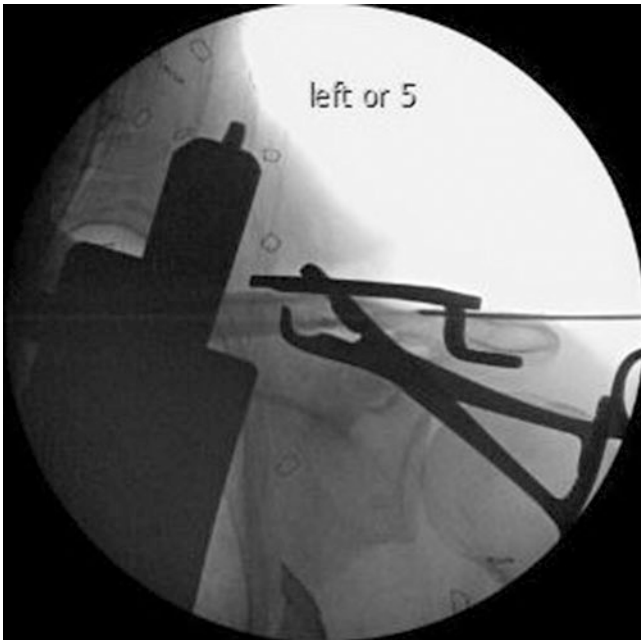


**Fig. 6.51** (a) Patient position after prepping and draping. (b) Incision for distal clavicle ORIF

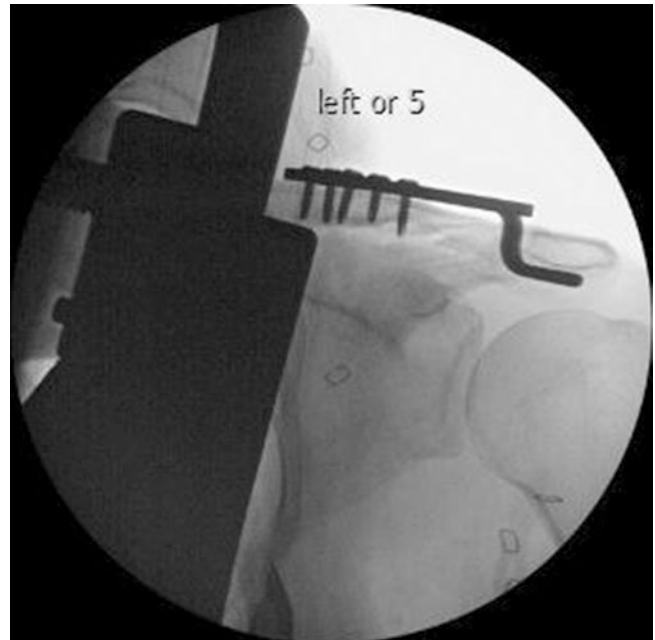


**Fig. 6.52** (a, b) Vertical plate positioning for insertion. (c) Plate held with lobster claw clamp





**Fig. 6.53** Intraoperative radiograph



**Fig. 6.55** Intraoperative radiograph showing final fixation

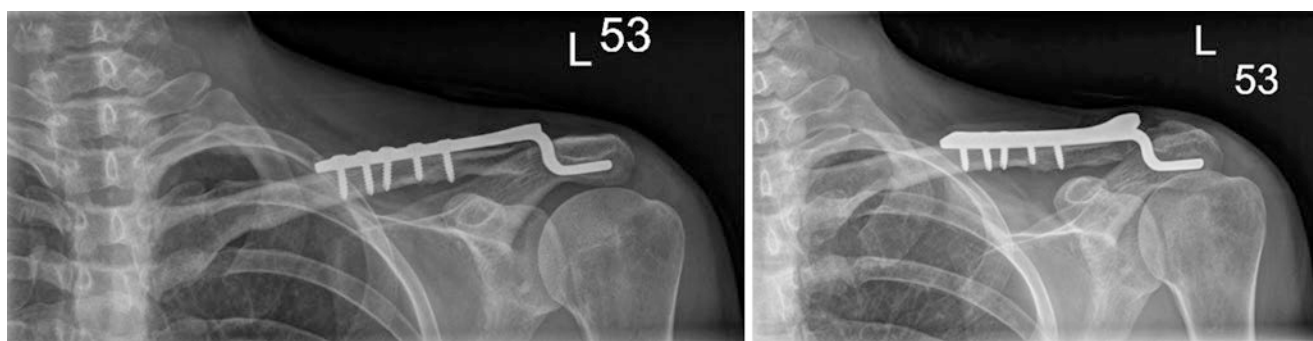


**Fig. 6.54** Positioning of C-arm to obtain intraoperative image





**Fig. 6.56** Follow-up radiographs



**Fig. 6.57** Radiographs of healed fracture

## References

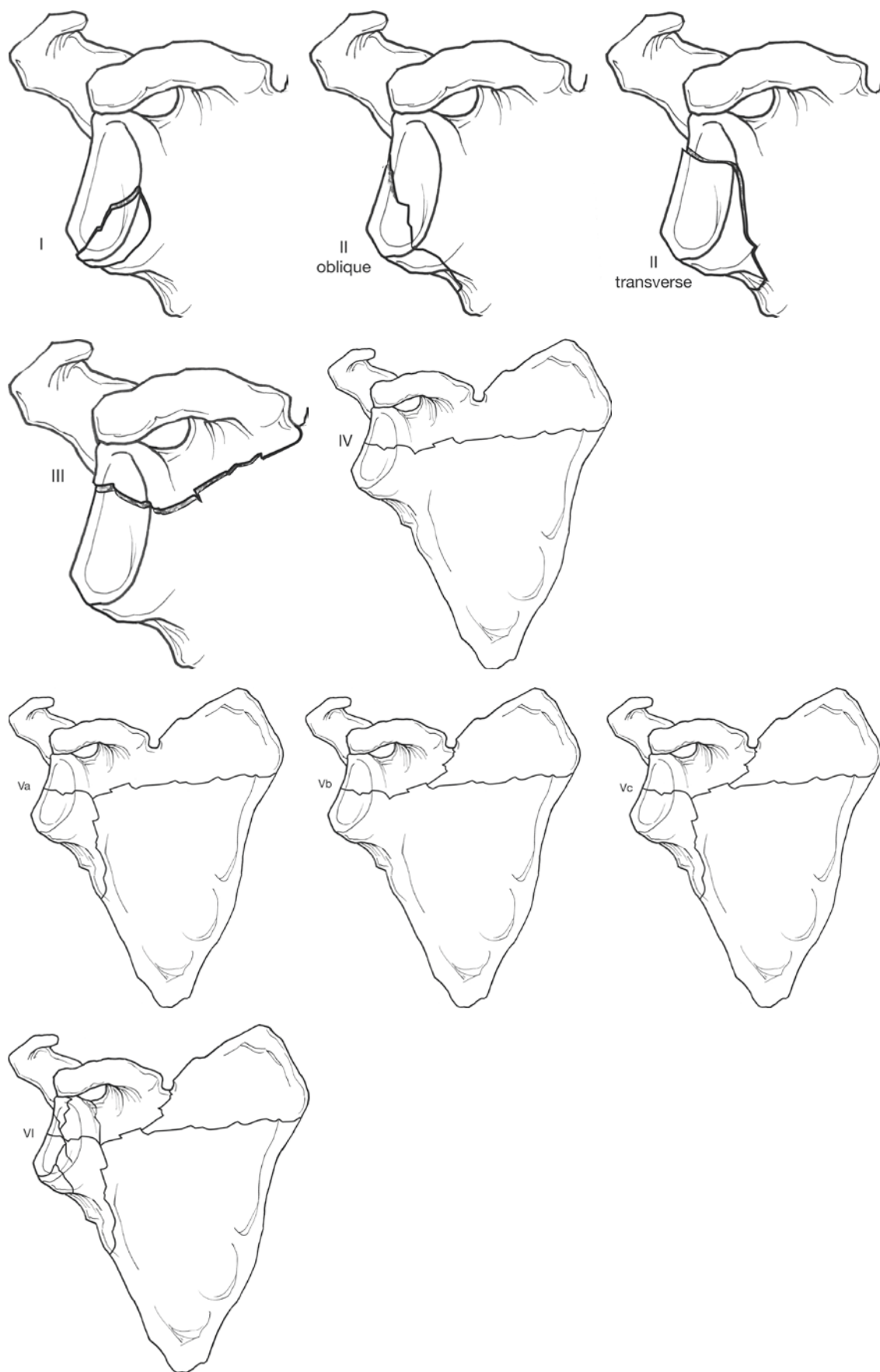
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### 7.1 Criteria for Surgical Intervention of Scapular Fractures

Scapular fractures, regardless of the anatomic location or displacement, rarely require surgical intervention [1, 2], though some authors have developed criteria for surgical intervention predicated upon fracture displacement,

glenopolar angle, medial glenoid displacement, and intra-articular glenoid fractures [3]. From a treatment standpoint, I have not found either the above recommendations or the following classification systems to be particularly helpful. Classifications have been presented by Ideberg and expanded upon by Goss [4–6] (Fig. 7.1).



**Fig. 7.1** Scapula body fractures. Classification by Ideberg [4] and Goss [5]



## 7.2 Treatment of Coracoid Fractures

The scapula can be broken down into the main anatomic locations: coracoid, acromion, body, scapular neck, and glenoid. Coracoid fractures are occasionally isolated; nearly all of these, whether displaced or nondisplaced, can be treated nonoperatively unless they are painful [7, 8]. I have operated on only one isolated coracoid process fracture, which was

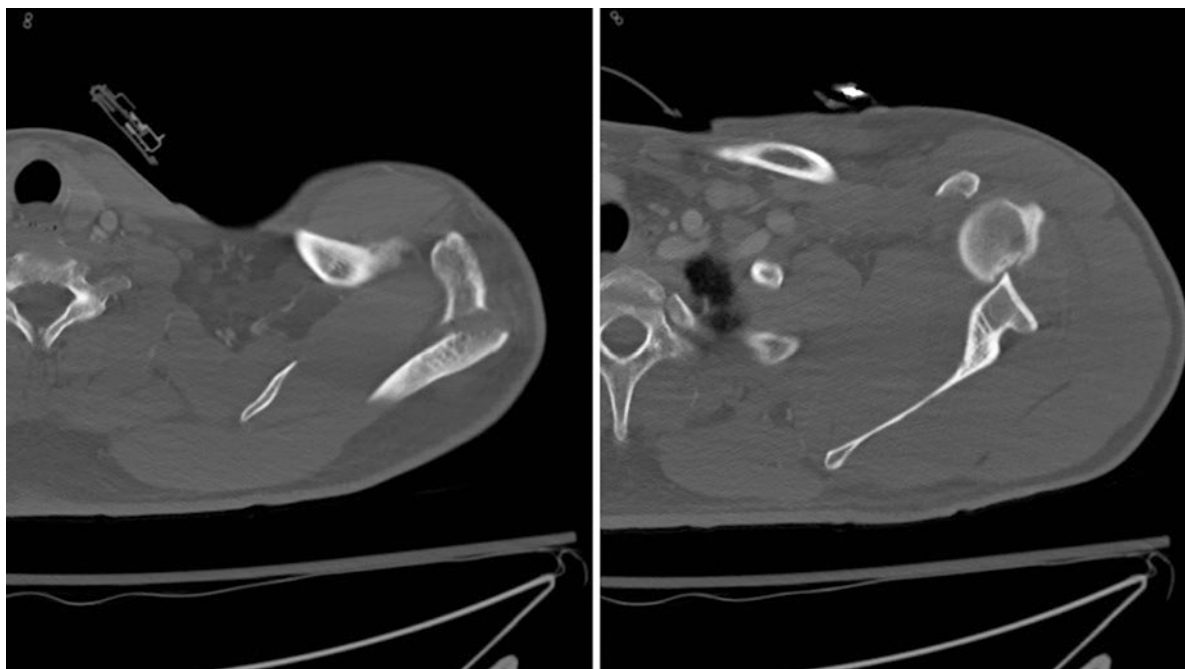
markedly displaced and prior to fixation was associated with pain consequent to biceps function. The coracoid process, with its connections to the coracoacromial (CA) ligament, pectoralis minor muscle, and conjoint tendon, tends to trampoline the coracoid away from its base; the smaller tip fractures, in particular, frequently proceed to nonunion (Figs. 7.2, 7.3, 7.4, and 7.5).



**Fig. 7.2** Left coracoid fracture. Anteroposterior (AP), Grashey, and axillary (*arrow*) views



**Fig. 7.3** Shoulder dislocations. AP and axillary radiographs of left shoulder anterior dislocations with associated coracoid and acromion fracture



**Fig. 7.4** Acromion and coracoid fractures, seen on CT scan



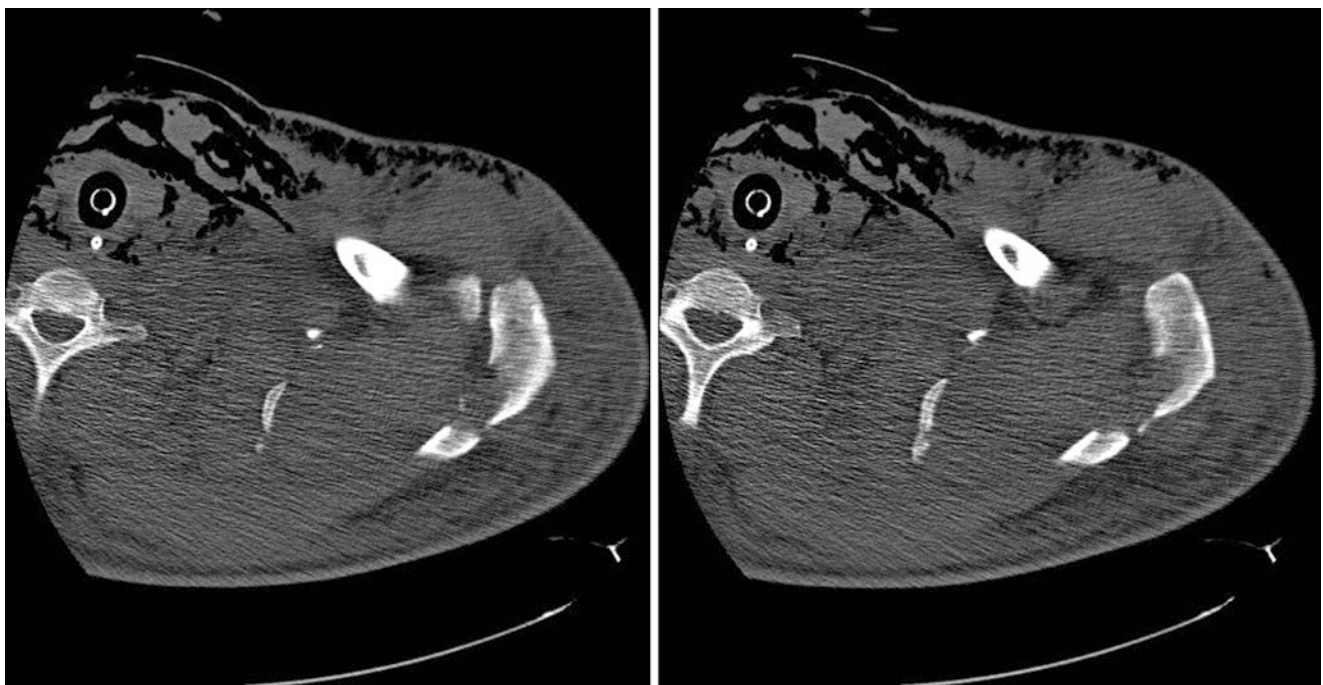
**Fig. 7.5** AP, Grashey, and axillary radiographs of left shoulder following reduction

Commonly, coracoid process fracture fixation is performed after fixation of associated fractures, such as displaced proximal humerus or glenoid fractures, utilizing the fracture as an osteotomy for access. Case presentations are demonstrated in Chap. 9. Acromion fractures in isolated scenarios occasionally benefit from surgical intervention because of the potential for the acromion to angulate toward

the rotator cuff. With these types of fractures, the tension banding technique may be helpful, as well as a contoured proximal humeral plate or locking plate, which allows the locking screw fixation to be placed at various angles to help support the acromion. Subsequent hardware removal is expected (Figs. 7.6, 7.7, 7.8, 7.9, 7.10, and 7.11).



**Fig. 7.6** AP radiograph of left shoulder with fractures of the clavicle and scapula

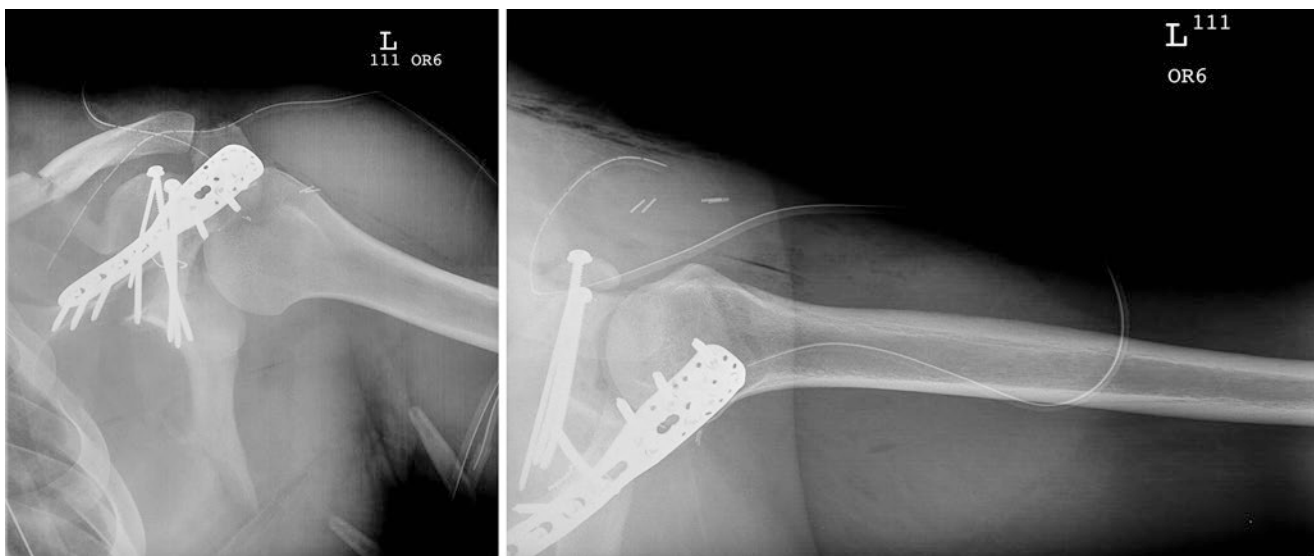


**Fig. 7.7** CT scan of left shoulder demonstrating acromion fracture

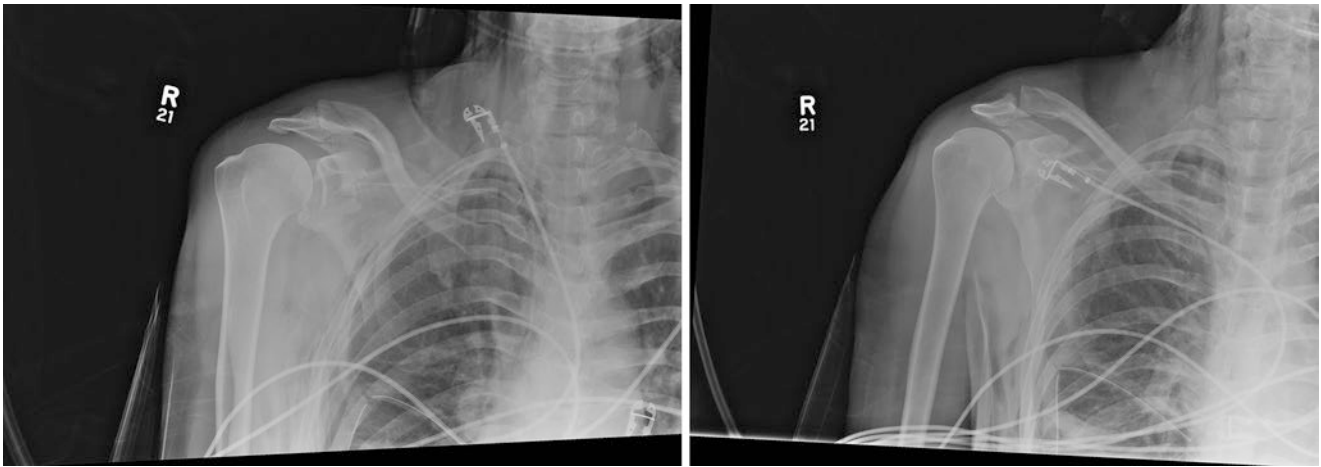




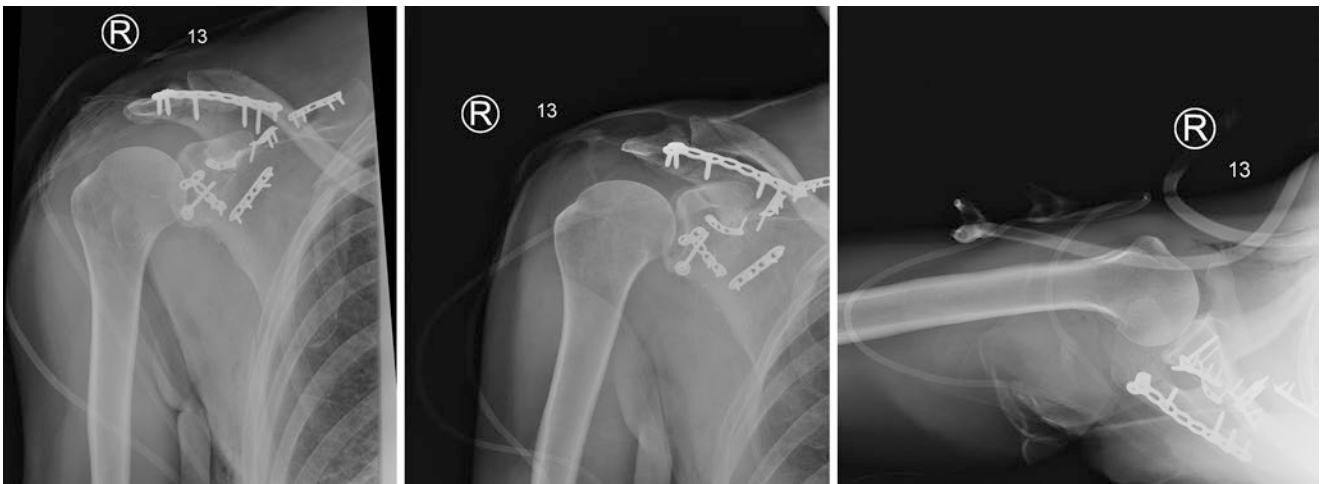
**Fig. 7.8** Coronal CT scan of left shoulder



**Fig. 7.9** AP and axillary radiographs following open reduction and internal fixation (ORIF) using a contoured proximal humerus plate



**Fig. 7.10** Grashey and AP radiographs demonstrating acromion, clavicle, and glenoid fractures



**Fig. 7.11** AP and Grashey radiographs following ORIF

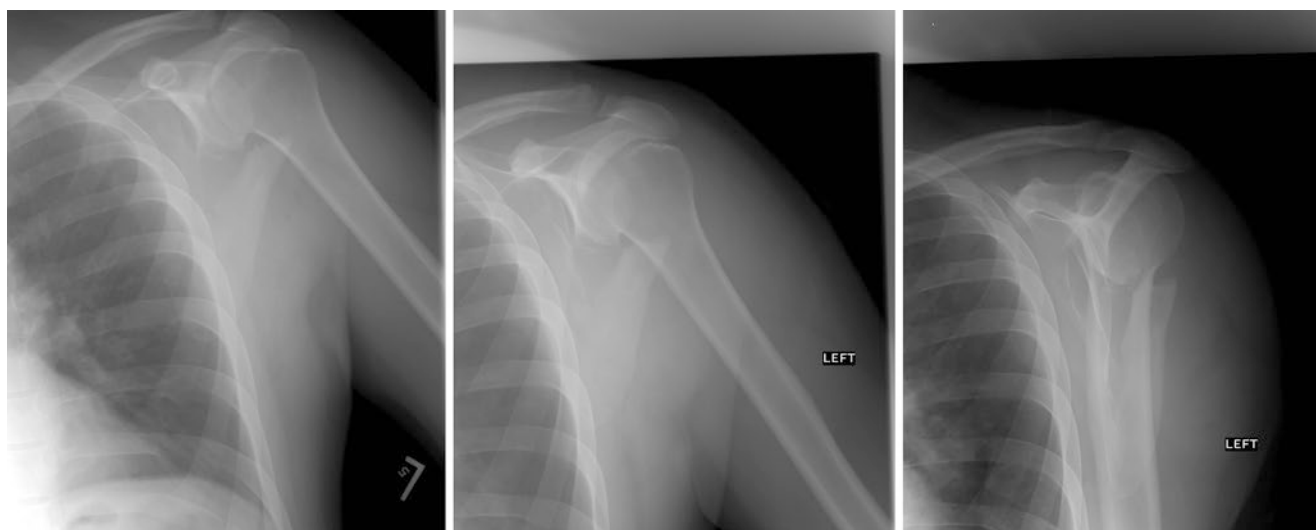
### 7.3 Treatment of Scapular Body Fractures

Fixation of the scapular body is more controversial. Suffice it to say, I have never operated on a scapular body unto itself. There are reports that compare nonoperative versus operative intervention [9–11]. Jones and Sietsema [11] cited 2 cm of displacement as an indication for surgery of the neck or body. Other advocates of surgical intervention cite the following in favor of surgical intervention [12–15]:

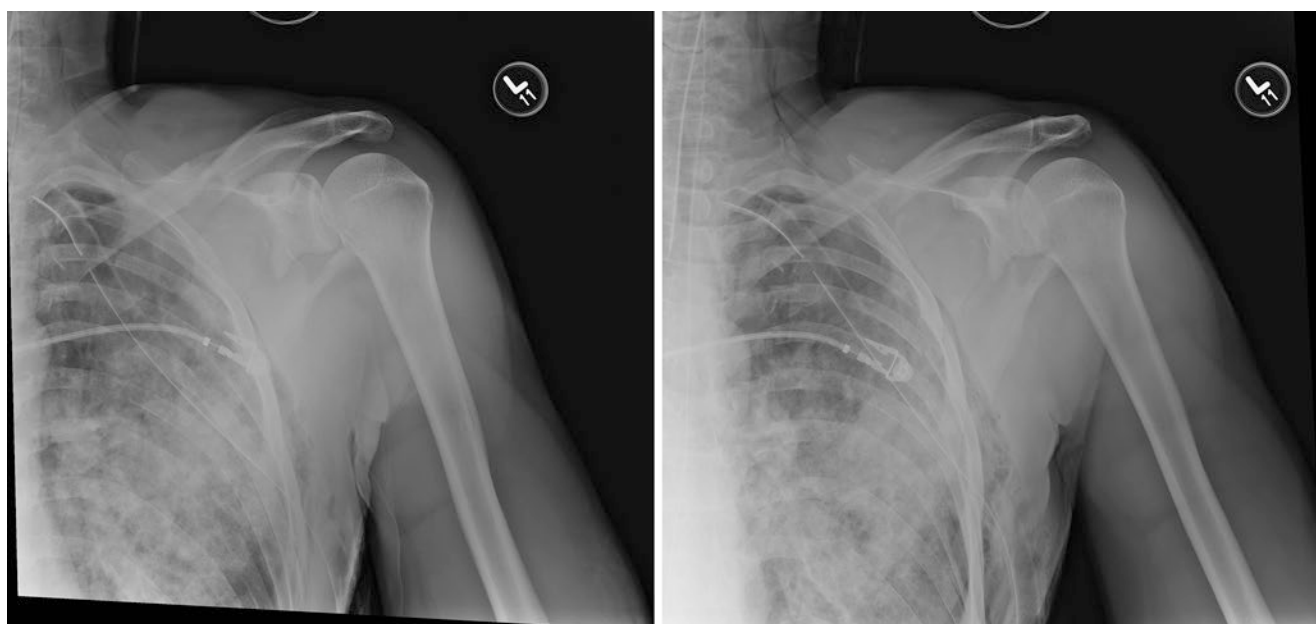
- Medialization of the glenohumeral joint > 20 mm
- Semi-coronal plane deformity > 45°

- Angulation > 30° and medialization > 15 mm
- Double suspensory shoulder complex disruption > 10 mm displaced
- Glenopolar angle > 22°
- Open fracture

The issue relative to medialization has been challenged, with the conclusion that medialization of the glenoid and neck, in fact, does not happen [16, 17] (Figs. 7.12, 7.13, and 7.14).

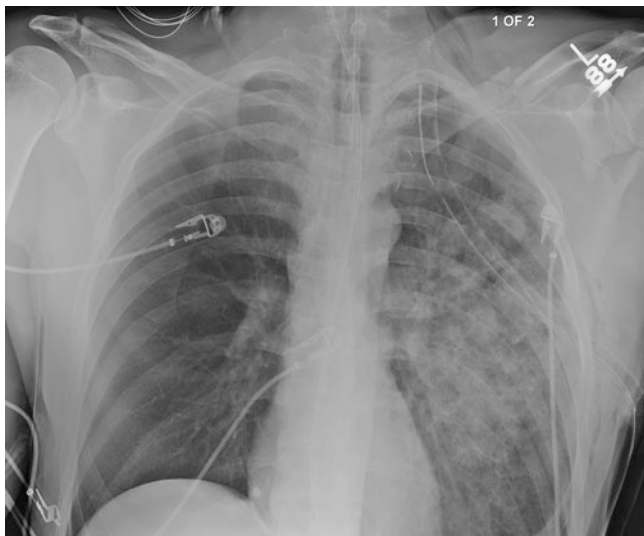


**Fig. 7.12** AP radiographs of left shoulder with lateral border of scapula lateralized



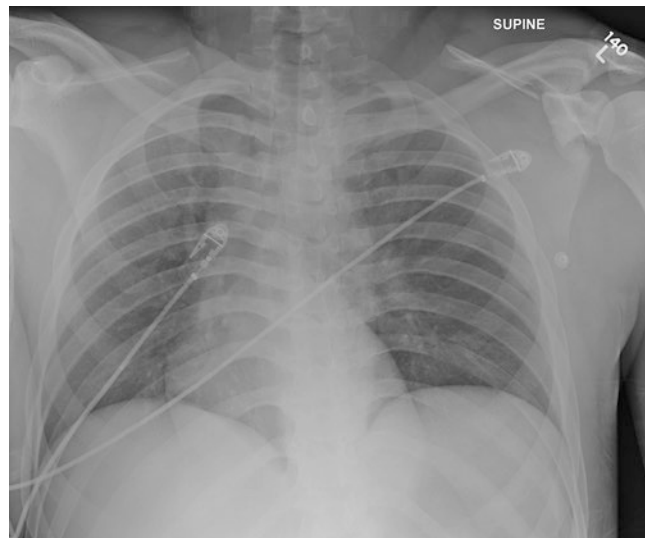
**Fig. 7.13** Grashey and AP radiographs of left shoulder with lateralized lateral border spike



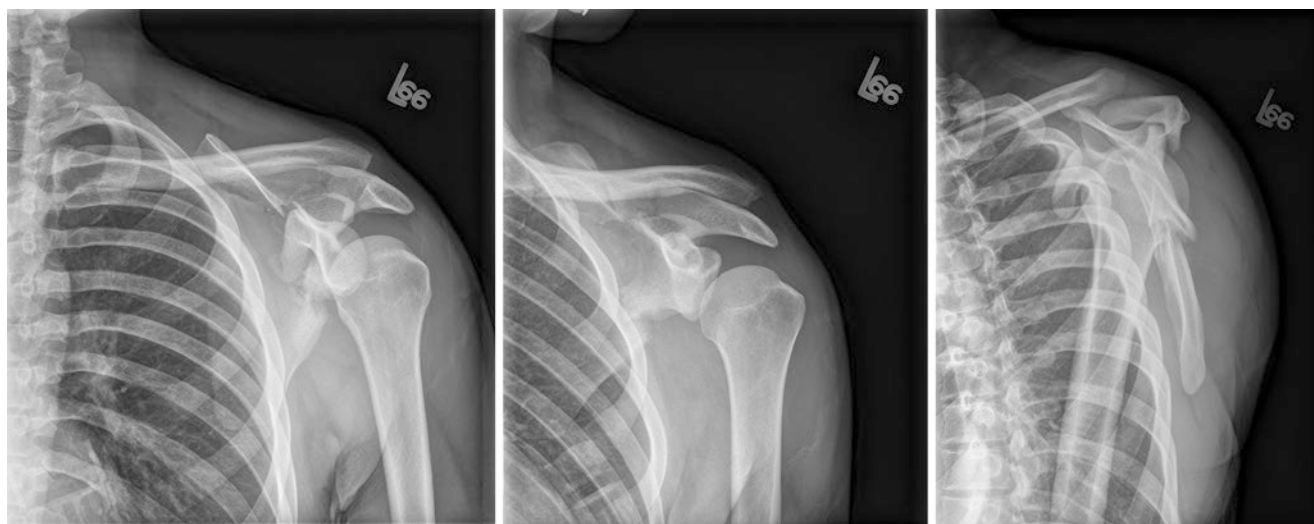


**Fig. 7.14** Chest radiograph revealing similar midline to glenoid distances

The prevailing treatment philosophy for scapular body fractures at Shock Trauma is nonoperative, regardless of displacement or angulation. Acknowledging that a formal prospective or exhaustive retrospective review has not been performed, the criteria above have been applied to our scapular fractures cases. Those that fell into the operative criteria have been able to return to manual labor, truck driving, and mechanics without limitation or subsequent surgery, thus raising questions as to the validity of the operative reasoning (Figs. 7.15, 7.16, 7.17, and 7.18).



**Fig. 7.15** Admission chest radiograph revealing left scapular neck fracture



**Fig. 7.16** Left shoulder radiographs demonstrating scapular body, glenoid neck, and acromioclavicular (AC) joint separation

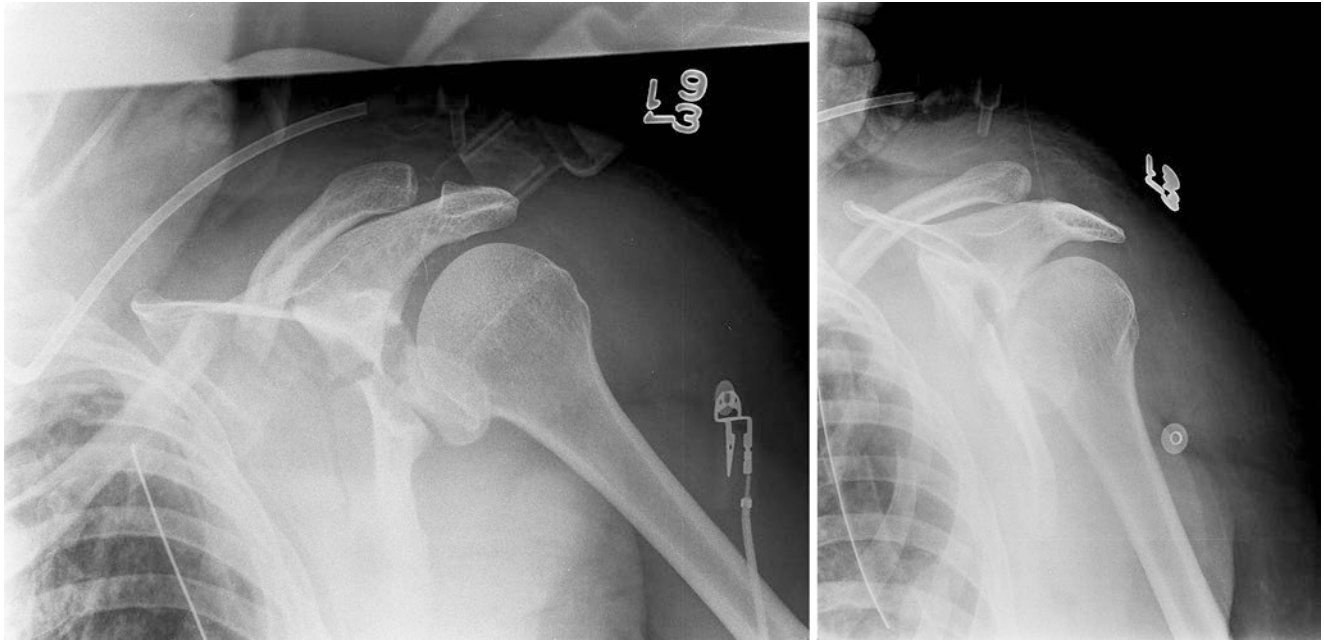
**Fig. 7.17** Three-dimensional (3D) CT scan of left shoulder revealing scapular body fractures on AC joint separation



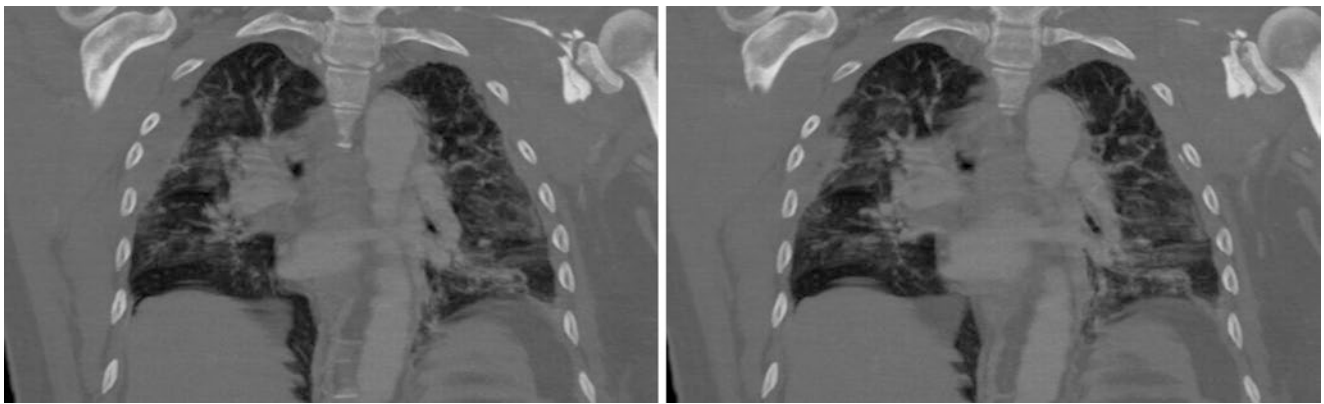
**Fig. 7.18** Radiographs of left shoulder following nonoperative treatment; the patient returned to his previous employment as a mechanic

## 7.4 Treatment of Glenoid Neck Fractures

The majority of glenoid neck fractures may be treated nonoperatively (Figs. 7.19, 7.20, 7.21, and 7.22).

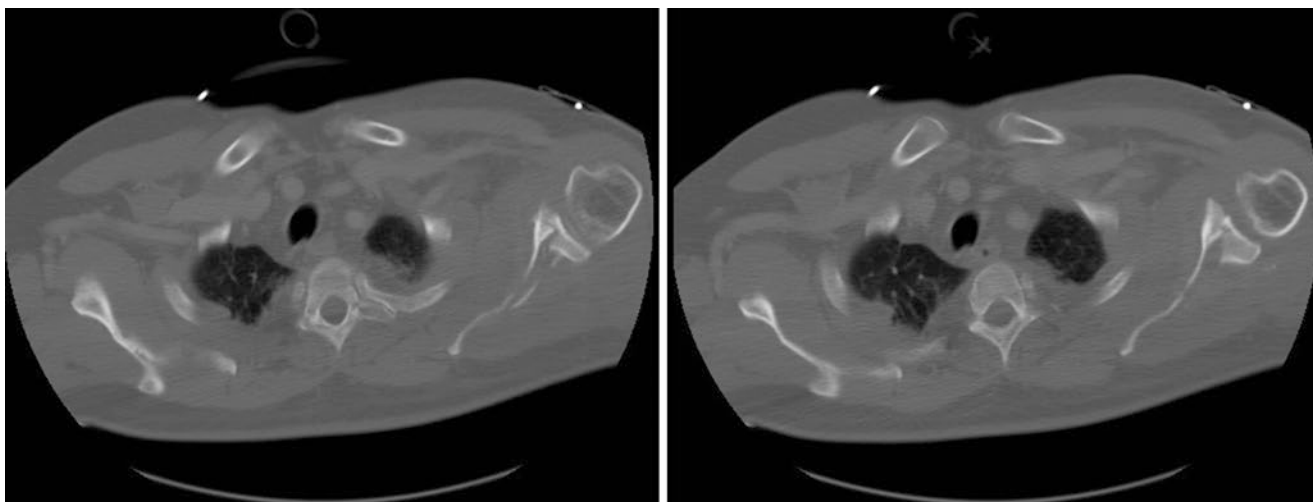


**Fig. 7.19** AP and Grashey radiographs of left shoulder glenoid fracture treated nonoperatively

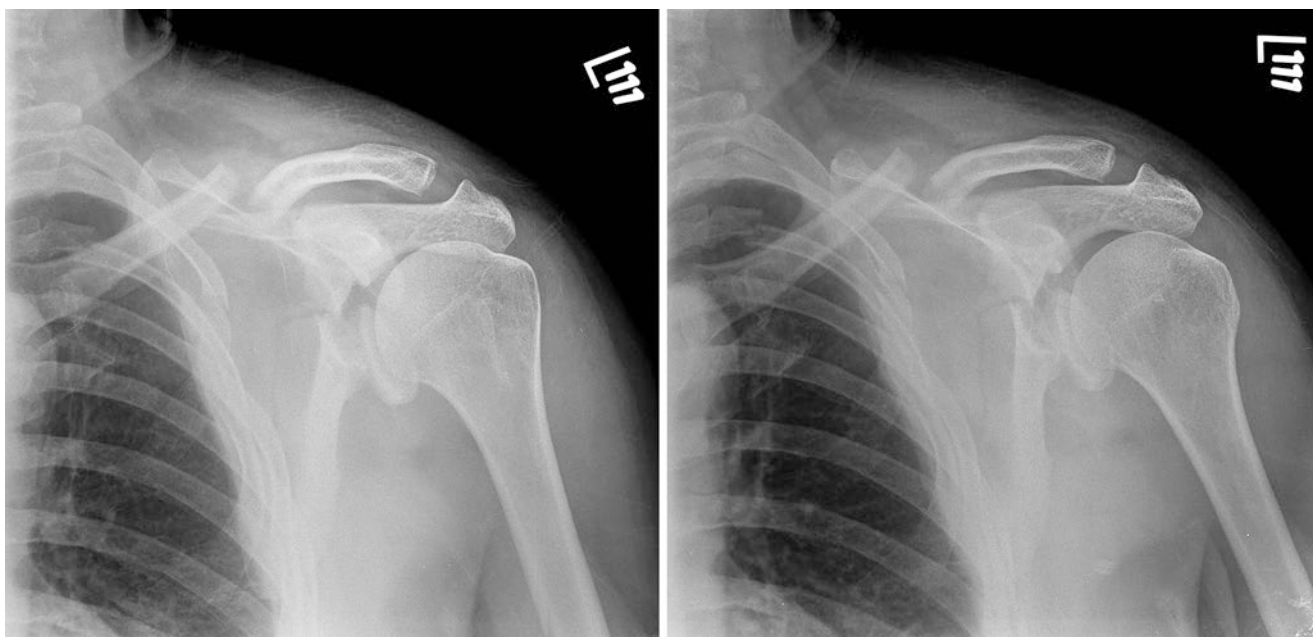


**Fig. 7.20** Chest CT scan revealing glenoid neck fracture



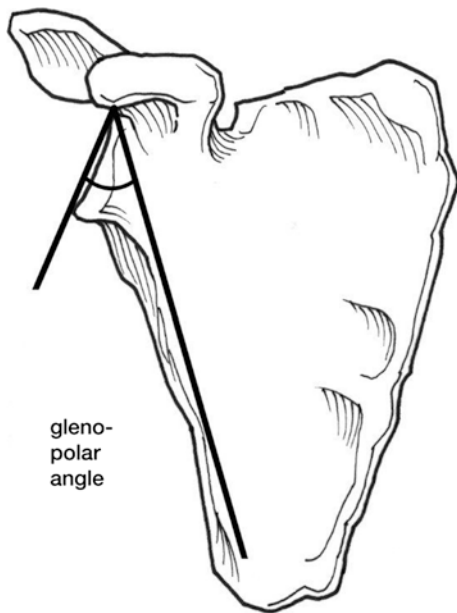


**Fig. 7.21** Axial CT scans of left shoulder glenoid neck fracture



**Fig. 7.22** Follow-up radiographs after patient returned to previous occupation

Some glenoid neck fractures may require surgical intervention, predicated upon the change in the mechanics and the potential for shearing when the glenopolar angle attains a certain degree (Fig. 7.23).



**Fig. 7.23** Glenopolar angle created by intersecting lines along lateral boarder at scapula and glenoid

Ada and Miller [18] cite 40° as an indication for surgical intervention, based on clinical studies. Surgery for isolated glenoid neck fractures is extremely rare; only twice have glenoid neck fractures treated at Shock Trauma required surgical intervention, both because the glenoid was facing anteriorly.

#### 7.4.1 Glenoid Intra-Articular Fractures

Intra-articular glenoid fractures occasionally need ORIF, predicated upon certain criteria. Various authors propose the following:

- Anavian *et al.* [19]: Gap or step-off on CT scan  $\geq 4$  mm
- Mayo *et al.* [6]: Displacement  $> 5$  mm, or any displacement associated with the subluxation of the humeral head
- Goss [5]: Step-off  $> 5$  mm; inferior fragment displacement inferiorly with the inferior subluxation of the humeral head
- Eglseider (personal experience): Step-off or gap of 3 mm, or posterior inferior subluxation of the humeral head regardless of fragment size

I use the 3-mm criterion because it is representative of the articular cartilage thickness, and therefore a “tolerable” step-off limit. I have utilized the criteria of step-off and subluxation in over 80 patients with glenoid fracture undergoing ORIF. The problem with all of the above studies, opinions, and subsequent recommendations is the lack of a control group who met criteria for operative intervention but who were treated nonoperatively.

#### 7.4.2 Glenoid Bankart and Anterior Rim Fractures

The other glenoid articular injury is the anterior fracture dislocation in which, effectively, there is a large Bankart fracture or an anterior rim fracture. If either occurs, two approaches may be used: arthroscopy for the smaller Bankart fracture or ORIF for larger anterior fragments.

### 7.5 Operative Approaches to the Scapula

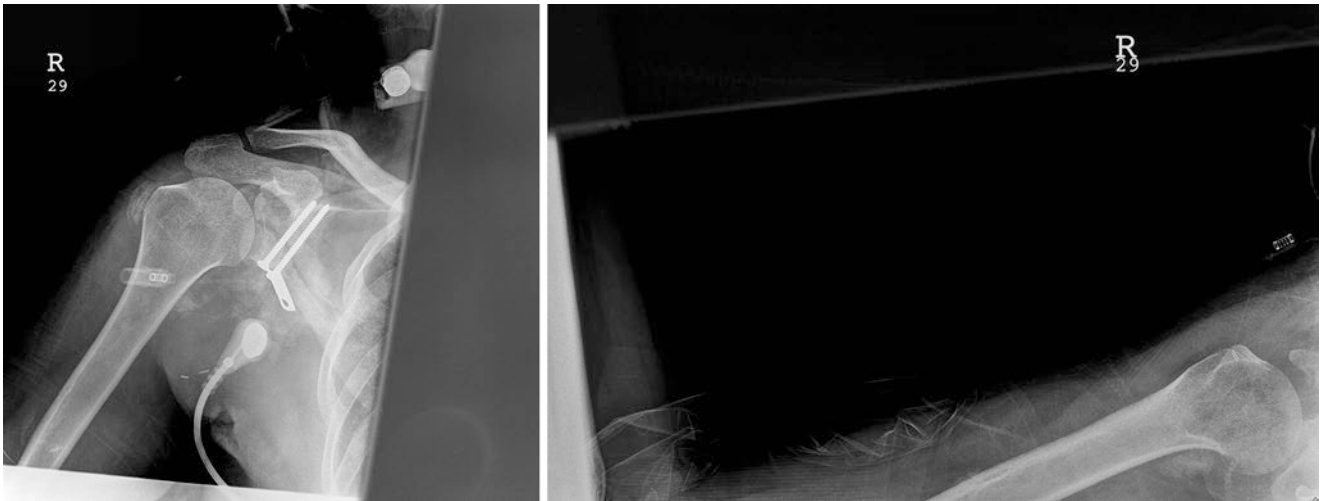
The posterior approach to the scapula is used for any intra-articular fracture exclusive of the large anterior rim Bankart fracture [20]. I have tried limited exposures, such as a straight exposure between the infraspinatus and the teres minor, but I found them very limiting when it was necessary to convert to a more extensive approach. As a disclaimer, I have used a trans-axillary approach for an inferior rim fracture, but this is a difficult approach used only in highly selective cases (Figs. 7.24, 7.25, and 7.26).



**Fig. 7.24** AP radiograph of right shoulder revealing intra-articular right glenoid fracture



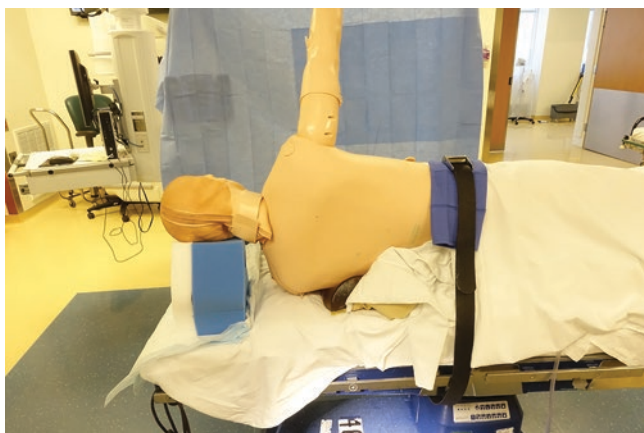
**Fig. 7.25** CT scan of right glenoid fracture



**Fig. 7.26** Radiographs following ORIF

Therefore my technique has become effectively to use a single utilitarian approach. The patient is positioned laterally on a beanbag with an axillary roll (Fig. 7.27).

The pre-draping is extensive, from the patient's ear to the iliac crest and slightly past the midline anteriorly and posteriorly (Fig. 7.28).



**Fig. 7.27** Lateral position with arm suspended and axillary roll in place



**Fig. 7.28** Pre-drape U-drape



A padded Mayo or a Spyder™ device can be used to hold the arm, which helps in distraction, allowing glenohumeral visualization (Figs. 7.29, 7.30, and 7.31).



**Fig. 7.29** Padded Mayo with drape taped to prevent migration of the drape when the arm is secured to a hook on the Mayo stand

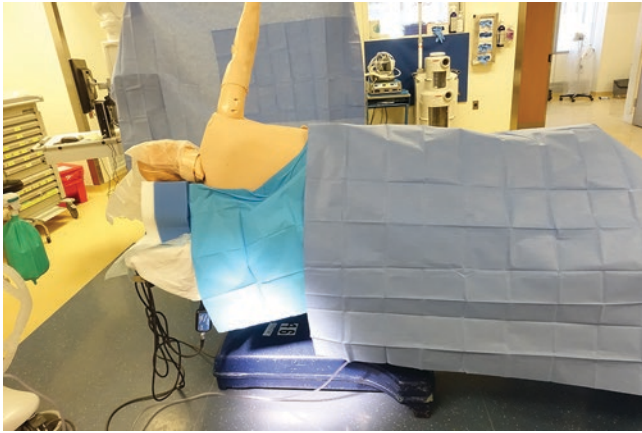


**Fig. 7.30** Padded Mayo with drape taped to prevent migration of the drape when the arm is secured to a hook on the Mayo stand



**Fig. 7.31** Padded Mayo with drape taped to prevent migration of the drape when the arm is secured to a hook on the Mayo stand

The anterior thorax is also prepped, in case the coracoid needs to be manipulated or approached (Figs. 7.32, 7.33, 7.34, 7.35, and 7.36).



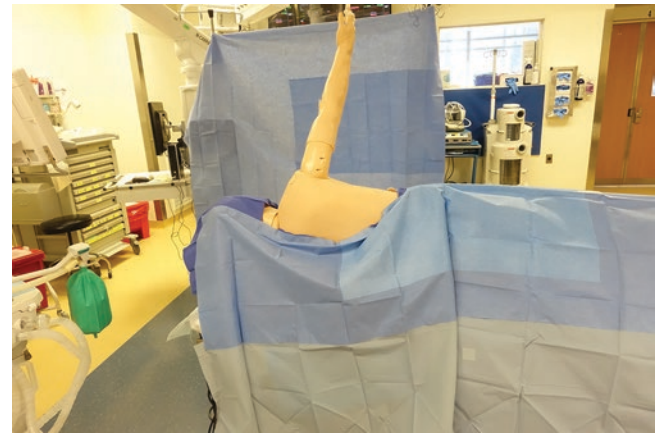
**Fig. 7.32** Body drape



**Fig. 7.33** Three-quarter drape over down arm



**Fig. 7.34** Four towels around perimeter



**Fig. 7.35** Split drape with tails up



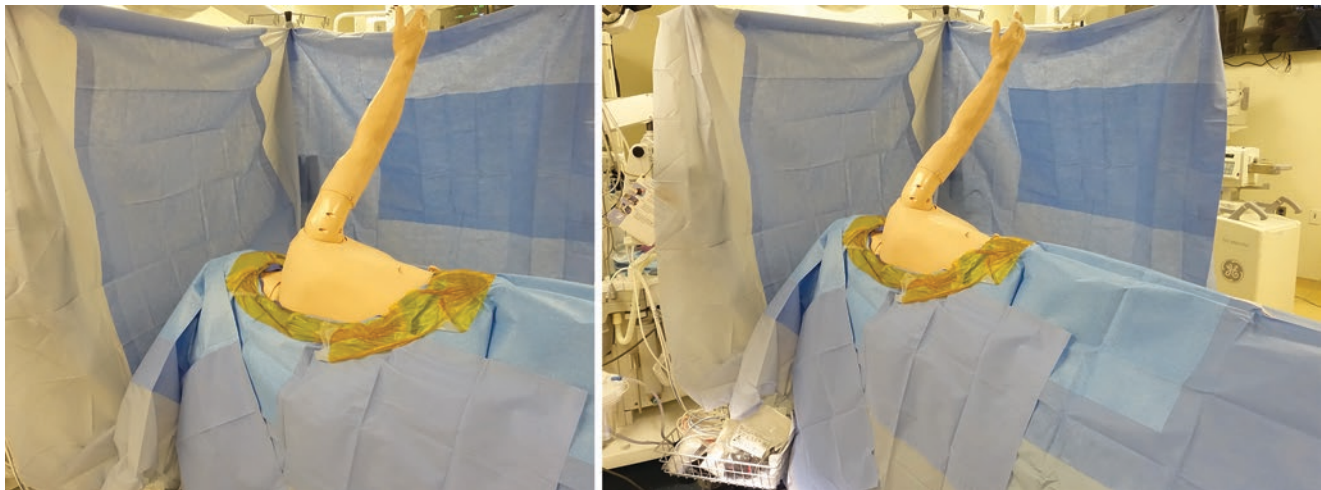
**Fig. 7.36** Split drape with tails down



The wide prepping is performed with Ioban™ used to seal the drape edges (Figs. 7.37 and 7.38).



**Fig. 7.37** Ioban® seals perimeter (The Ioban® was not applied to the “volunteer” we borrowed because it didn’t come off well.)



**Fig. 7.38** Anesthesia barrier drape

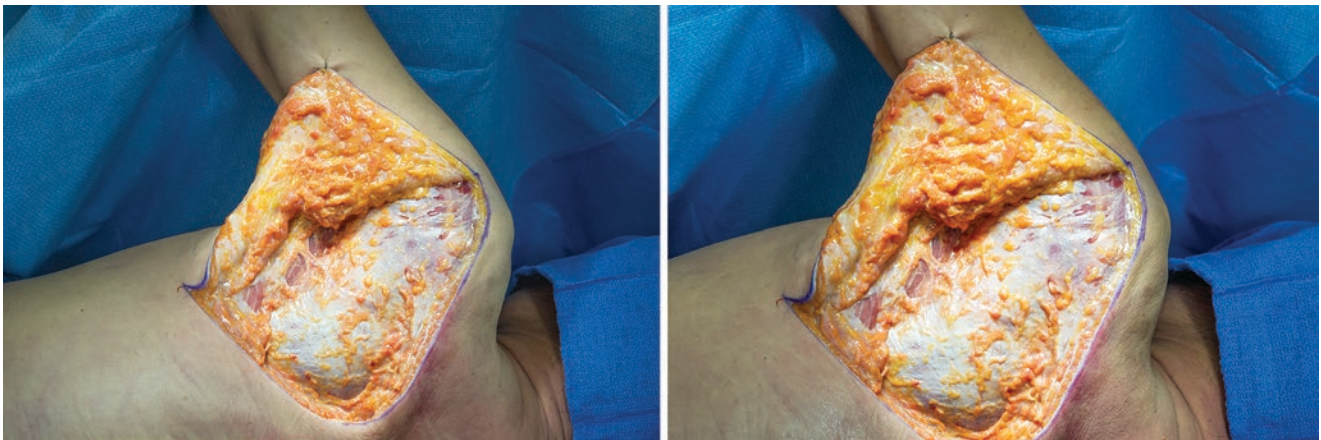


The arm, abducted and slightly internally rotated, rests on a padded Mayo. The incision is outlined from the acromion, across the scapular spine, down the medial border of the scapula, and slightly curved at the inferior angle of the scapula (Fig. 7.39).



**Fig. 7.39** Cadaver demonstration of posterior approach to glenoid, skin incision

Once the incision is carried out, I use two Bovies to minimize the amount of bleeding. The skin flap is elevated over the fascia of the deltoid, infraspinatus, teres minor and major, and latissimus dorsi (Fig. 7.41).



**Fig. 7.41** Skin flap raised over fascia

From a practical standpoint, I staple a sponge to the patient in order to collect any blood that drains during the intervention (Fig. 7.40).



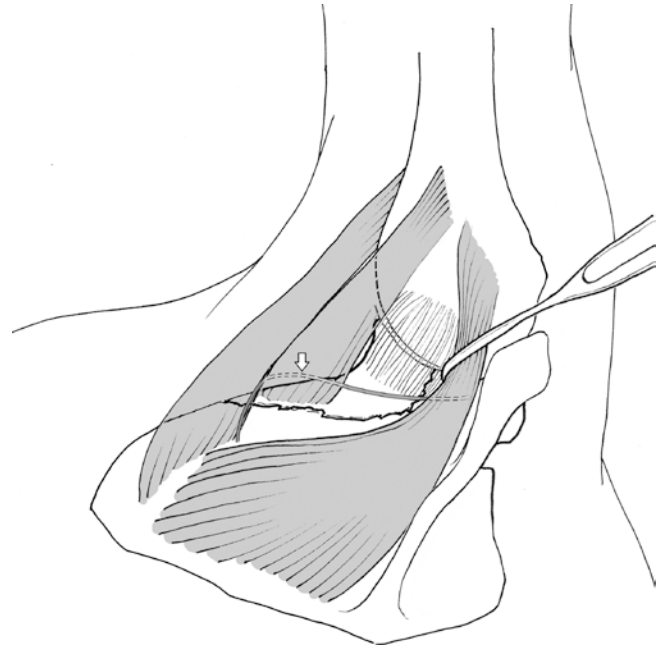
**Fig. 7.40** Sponge positioned to collect blood

The skin is sutured to the patient's arm with a #2 nylon, which helps reflect the flap. With the flap elevated from medial to lateral, those familiar with parascapular or scapular flaps will be able to visualize the perforators coming

from the circumflex scapular artery in the interval between the teres major and teres minor (Figs. 7.42 and 7.43).



**Fig. 7.42** Circumflex scapular artery perforator



**Fig. 7.43** Diagram of circumflex scapular artery crossing between teres major and teres minor

### 7.5.1 Developing the Plane between the Teres Minor and Infraspinatus

Knowing the interval between the teres major and teres minor is useful in developing the subsequent appropriate plane between the teres minor and the infraspinatus. This can be a difficult plane to develop, as there is a tendency to elevate the infraspinatus along with the deltoid. I elevate the

deltoid off the scapular spine. Sometimes the easier approach is to identify a dip or contour to the deltoid distally, incise the fascia, do a blunt dissection between the deltoid and the infraspinatus, and then elevate the deltoid and reflect this laterally with sutures to allow visualization (Figs. 7.44, 7.45, and 7.46). The initial impression is that this is an extensive approach; it is, considering the paucity of fixation commonly utilized.

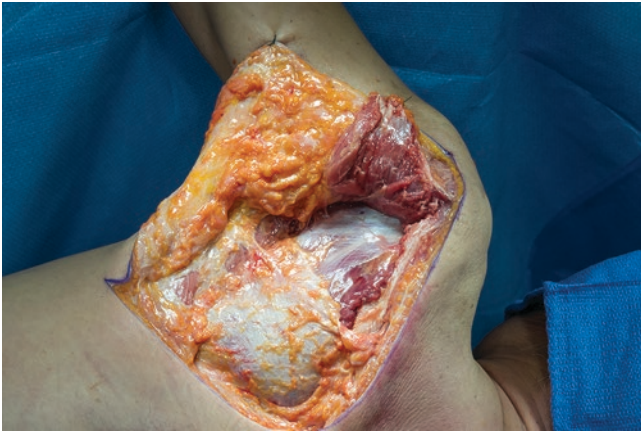


**Fig. 7.44** Defining plane between deltoid and infraspinatus



**Fig. 7.45** Deltoid elevation

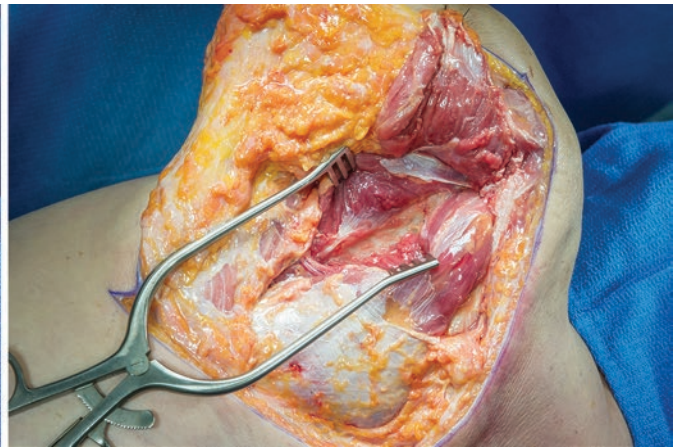




**Fig. 7.46** Deltoid reflected

Once the deltoid is reflected, the interval to the glenoid is carried out. As previously noted, the circumflex scapular perforator is used to identify the appropriate interval,

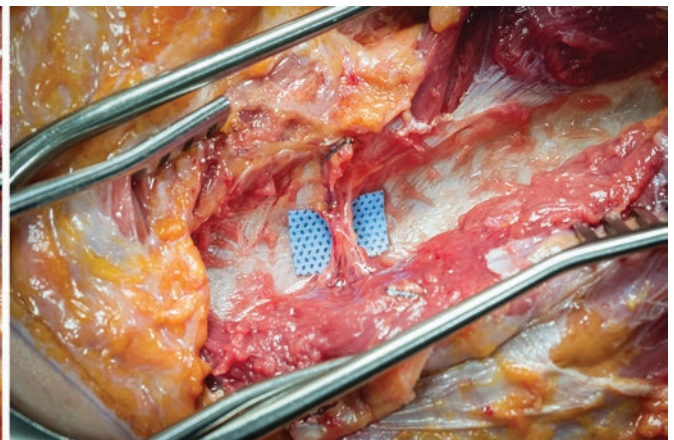
allowing development of the plane between the teres minor and the infraspinatus (Fig. 7.47).



**Fig. 7.47** Interval between teres minor (*black arrow*) and infraspinatus (*white arrow*)

If you see the circumflex artery, you know the teres minor/infraspinatus interval is medial. There are numerous branches

from the circumflex scapular system that need to be controlled, particularly distally along the scapular border (Fig. 7.48).

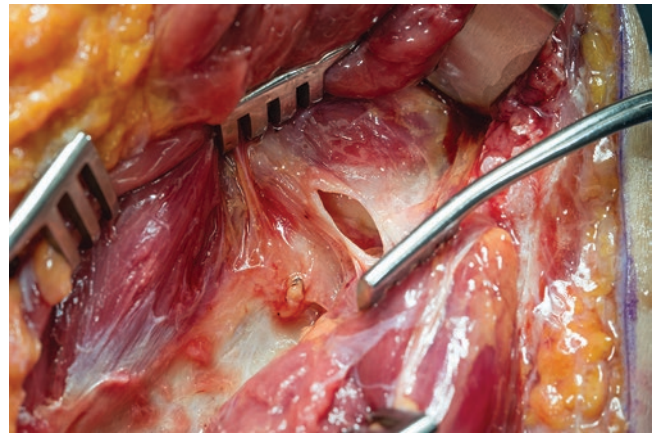


**Fig. 7.48** Perforators from the circumflex scapular artery



### 7.5.2 Bone Reduction and Fixation

Perforators are quite useful when harvesting bone along the lateral border of the scapula. With self-retaining retractors in the interval between the teres minor and the infraspinatus, the posterior capsule is approached. I generally perform an arthrotomy, allowing visualization of the humeral head, but with great effort to minimize labral division (Figs. 7.49 and 7.50).



**Fig. 7.49** Arthrotomy transversely in capsule, above labrum



**Fig. 7.50** Capsule with a T-shaped incision, allowing humeral head visualization

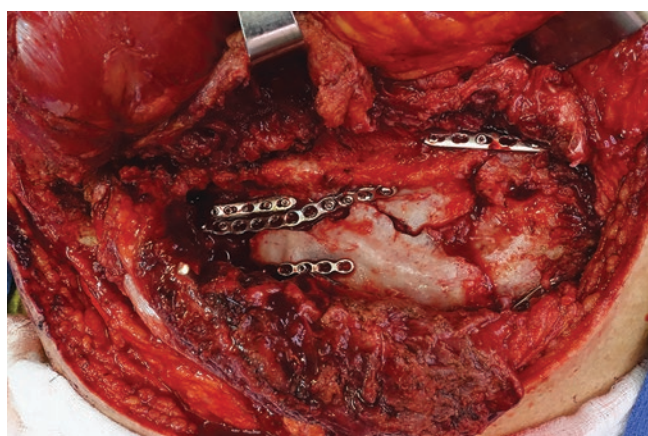
Depending on the fracture orientation, it can be difficult to gain access to the more superior component of the glenoid complex, and great care must be taken to prevent any injury of the suprascapular nerve as it comes around the base of the scapular spine (Fig. 7.51).



**Fig. 7.51** Suprascapular artery and nerve coursing around the scapular spine and traveling into the infraspinatus

When possible, I often put a Steinmann pin in the base of the neck to help retract the soft tissues. Because of the depth of the joint incision and the potential for the heads of those on the operative team to block visualization, a head lamp is used. Threaded Steinmann pins and large lamina distractors or spreaders also may be used to allow direct joint visualization.

Occasionally, body fixation is carried out first, to build up a bone stock laterally to allow fixation of the glenoid fragments back to the body. Frequently I use the 2.4-mm and 2.7-mm locking system, along with mini-fragment plates for limited internal fixation to rebuild the body out to the lateral border fragment and then the neck and glenoid (Fig. 7.52).



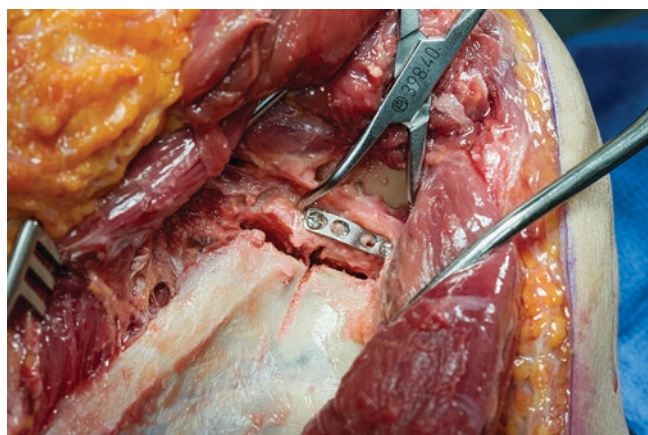
**Fig. 7.52** Clinical example of building body with mini-fragment plates

Threaded Steinmann pins are quite helpful to use as joysticks, as there is a tendency for the anterior fragments to sag away anteriorly (Fig. 7.53).

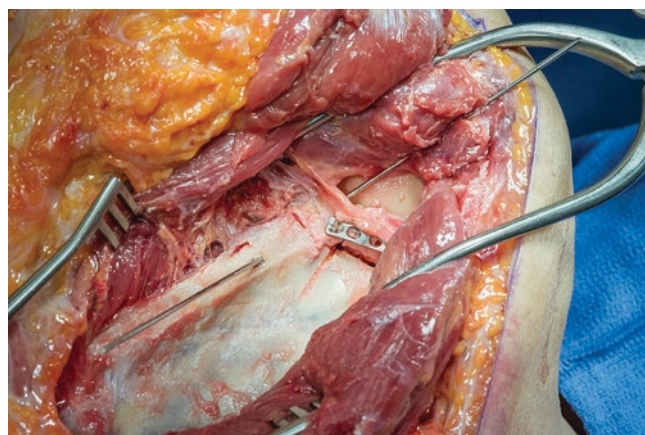


**Fig. 7.53** Threaded Steinmann pins in fragments to use as joysticks

I also use interosseous wires with sequential tightening to deliver the fragments back to each other. Fixation is then carried out with a variety of mini-fragment plates predicated upon fragment size (Figs. 7.54, 7.55, 7.56, and 7.57).

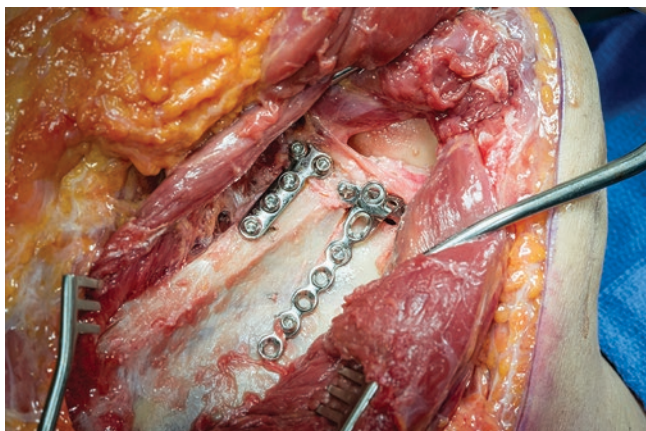


**Fig. 7.54** Mini-fragment plate 2.0 mm across articular fragments

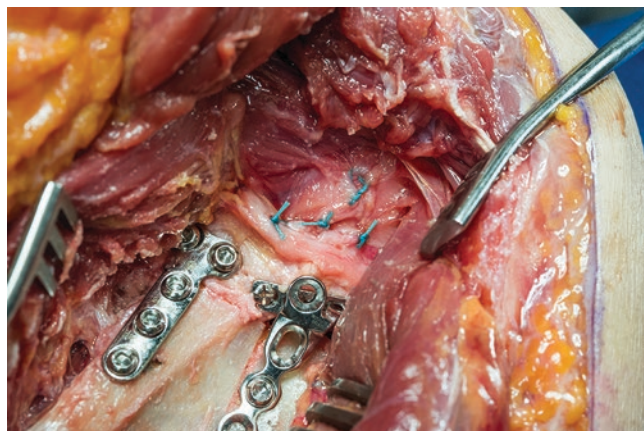


**Fig. 7.55** Kirschner wire (K-wire) fixation of articular fragment to body





**Fig. 7.56** Plate fixation

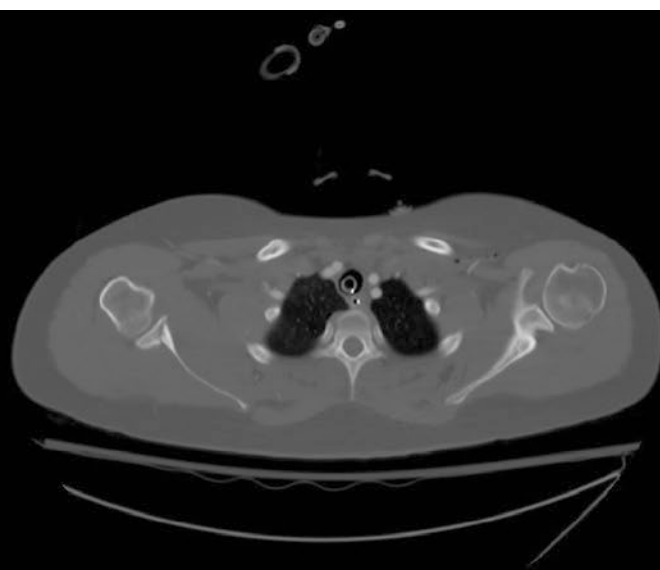
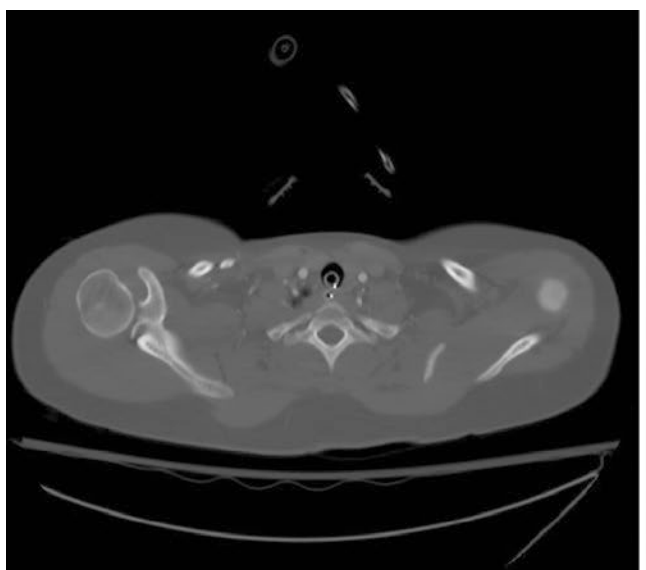


**Fig. 7.57** Repair of capsule with #0 or #1 Ethibond®

Typically, the lateral border is fixed definitively with either a 2.4-mm or 2.7-mm locking plate, sometimes using a T type to capture the inferior portion of the neck and glenoid (Figs. 7.58, 7.59, 7.60, 7.61, 7.62, 7.63, and 7.64).

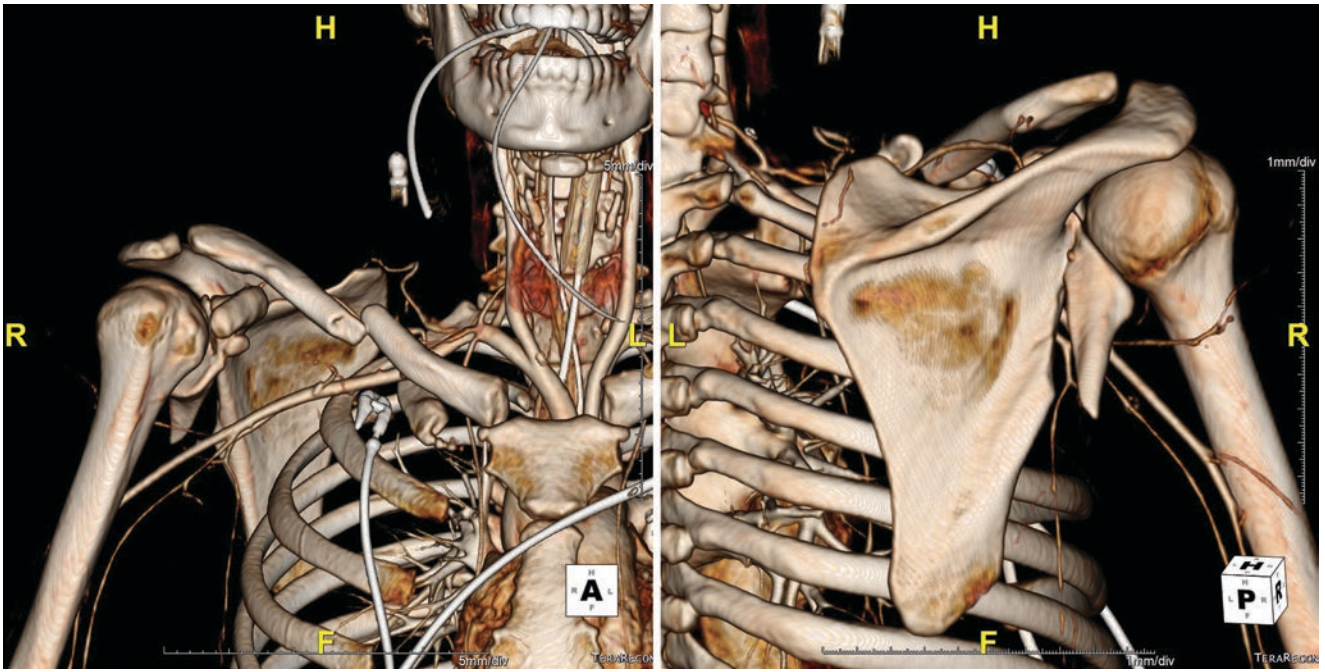


**Fig. 7.58** Injury radiographs of intra-articular right glenoid fracture



**Fig. 7.59** CT scan of right glenoid fracture





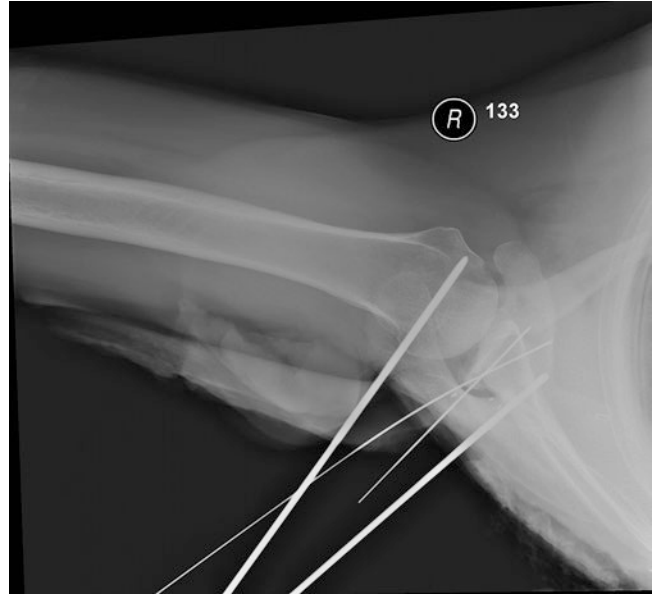
**Fig. 7.60** 3D CT scan of right glenoid fracture



**Fig. 7.61** Radiographs following ORIF with lateral-border, 2.4-mm locking plate



**Fig. 7.62** CT scan of patient with small posterior fragment with posterior subluxation



**Fig. 7.63** Intraoperative radiograph



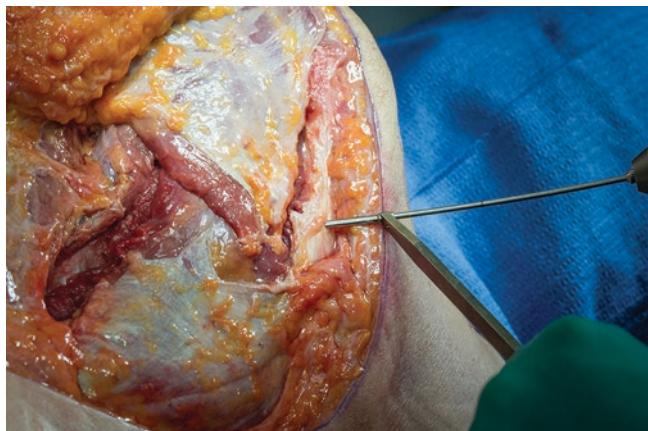
**Fig. 7.64** Radiographs following ORIF with locking T plate

### 7.5.3 Closing Following Fixation

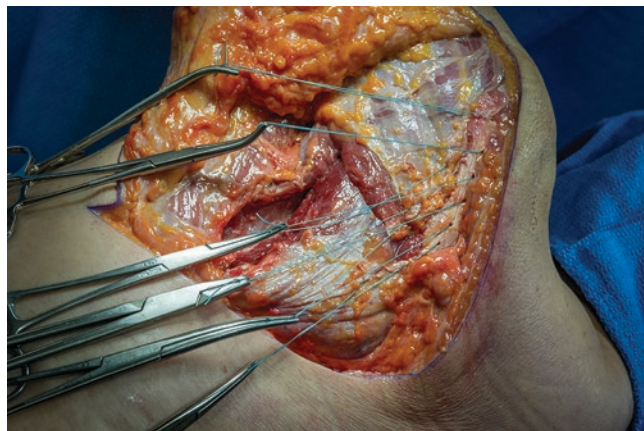
I endeavor to obtain axillary and posteroanterior (PA) intra-operative radiographs, not C-arm, though this is sometimes difficult because of patient positioning. Once the fixation is completed, I perform jet lavaging and close the capsule with #0 or #1 Ethibond®. It should be noted that the amount of infraspinatus elevation is predicated upon the fractures, and I

make great efforts not to strip the infraspinatus off the inferior aspect of the scapular spine, as this creates opportunity for necrosis of the infraspinatus.

Depending on the degree of infraspinatus elevation, the fascial approximation is performed. I reattach the deltoid through the drill holes with #0 or #2 Ethibond®. Typically, I make four or five drill holes (Figs. 7.65, 7.66, and 7.67).



**Fig. 7.65** Drilling holes with 2.0- or 2.5-mm drill bit for deltoid sutures



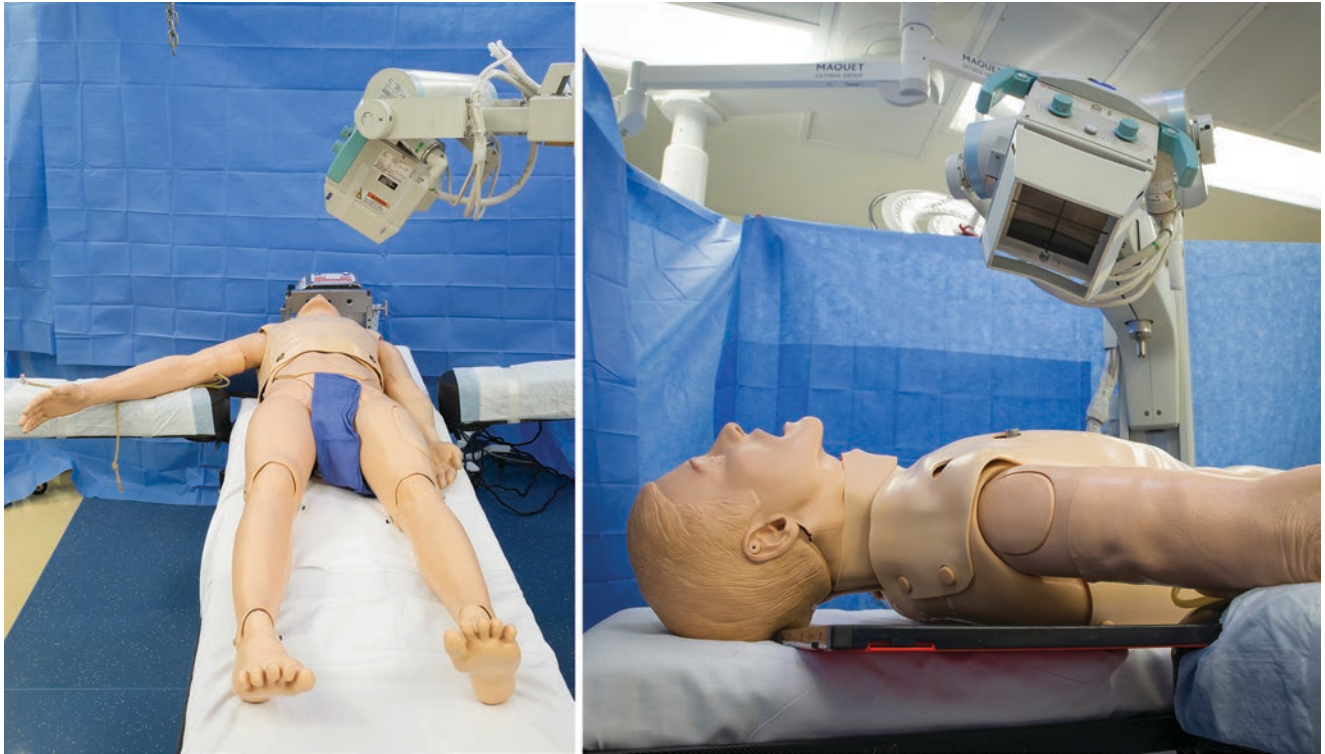
**Fig. 7.66** Sutures placement for deltoid repair



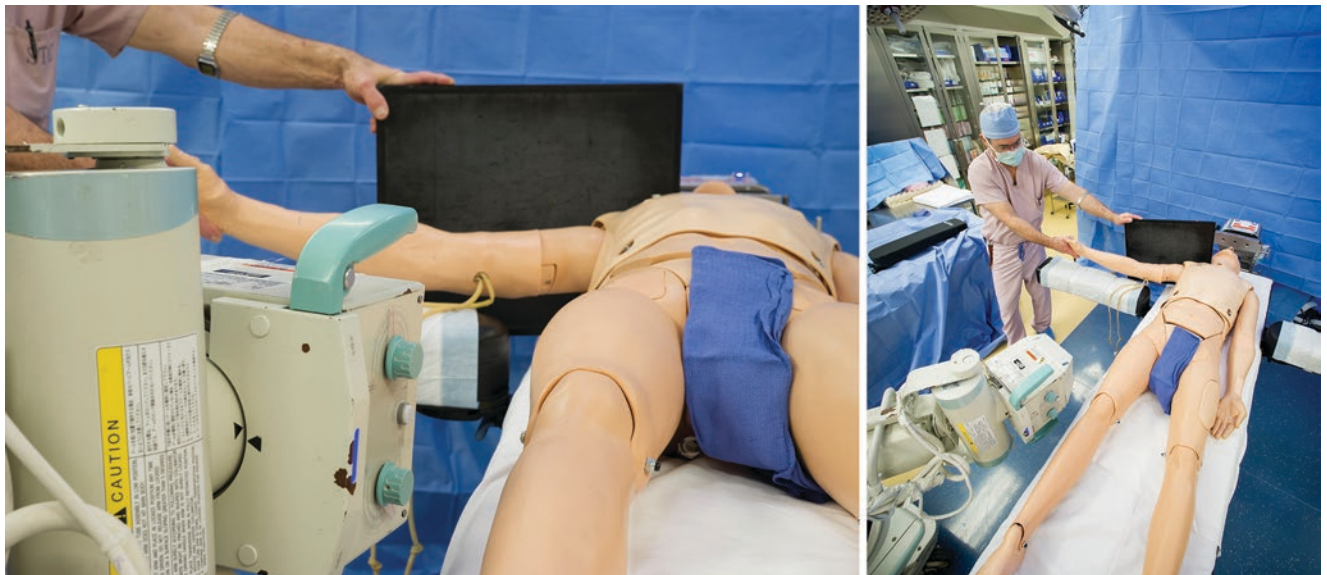
**Fig. 7.67** Sutures tied



The skin is then closed over two medium Hemovac drains. After closure and dressings, the patient is placed supine, and Grashey and axillary radiographs are obtained, with the back table remaining sterile (Figs. 7.68 and 7.69).



**Fig. 7.68** Grashey radiograph



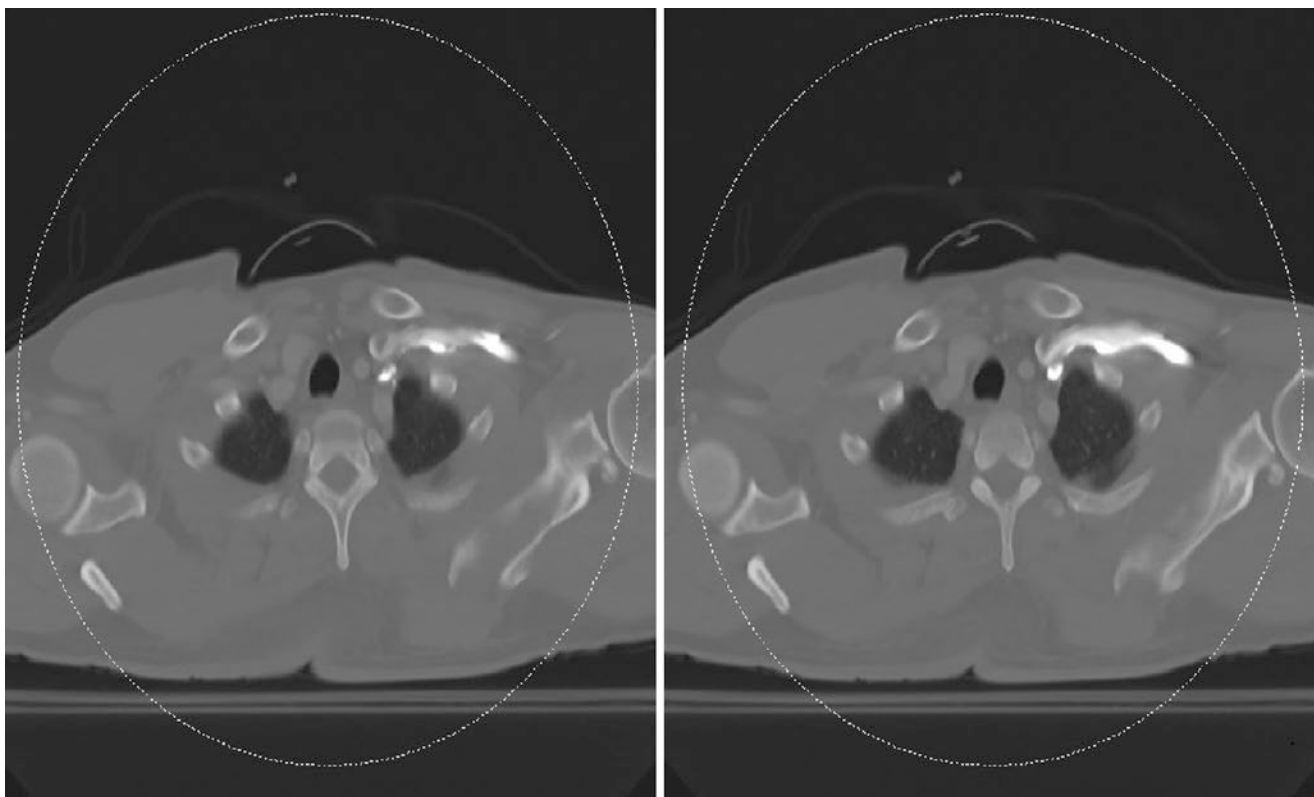
**Fig. 7.69** Axillary radiograph. Note sterile back table; surgeon should be wearing a lead apron

**7.5.4 Clinical Examples** (Figs. 7.70, 7.71, 7.72, 7.73, 7.74, 7.75, 7.76, 7.77, 7.78, 7.79, 7.80, 7.81, 7.82, 7.83, 7.84, 7.85, 7.86, 7.87, 7.88, 7.89, 7.90, 7.91, 7.92, 7.93, 7.94, 7.95, 7.96,

7.97, 7.98, 7.99, 7.100, 7.101, 7.102, 7.103, 7.104, 7.105, 7.106, 7.107, 7.108, 7.109, and 7.110)

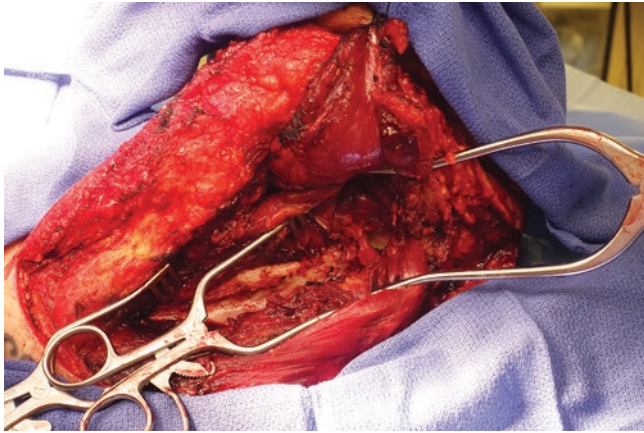


**Fig. 7.70** Injury radiographs of left shoulder demonstrating posterior glenoid fragment

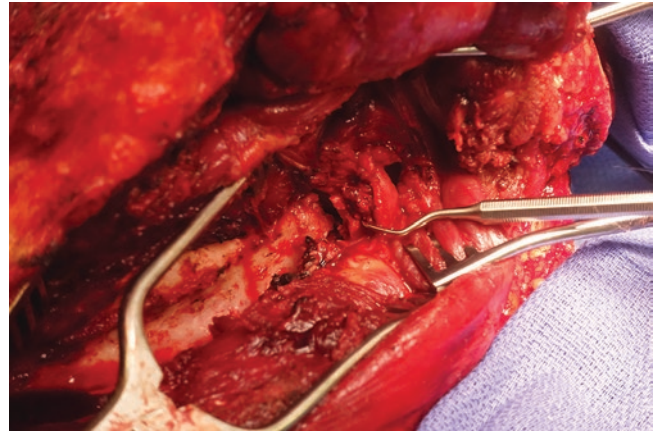


**Fig. 7.71** Screening chest CT scan that “picked up” the posterior glenohumeral subluxation, consistent with one of the criteria for ORIF

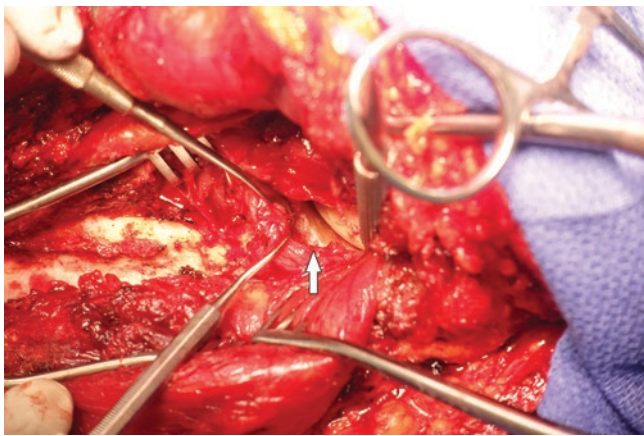




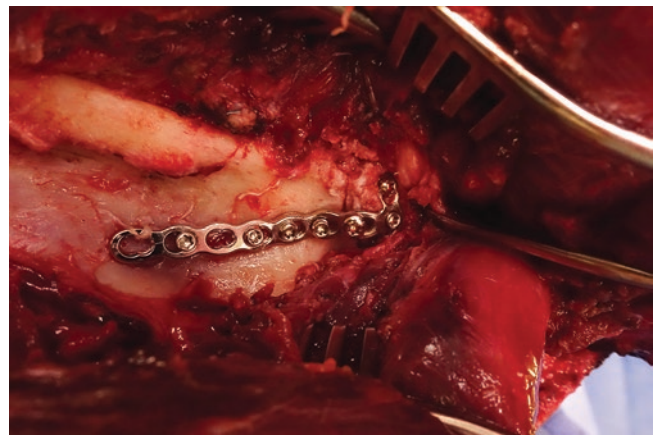
**Fig. 7.72** Surgical approach to left glenoid posterior fracture subluxation with reflected deltoid. Retractor in teres minor subscapularis interval. Humeral head (*arrow*) is visible through capsulotomy



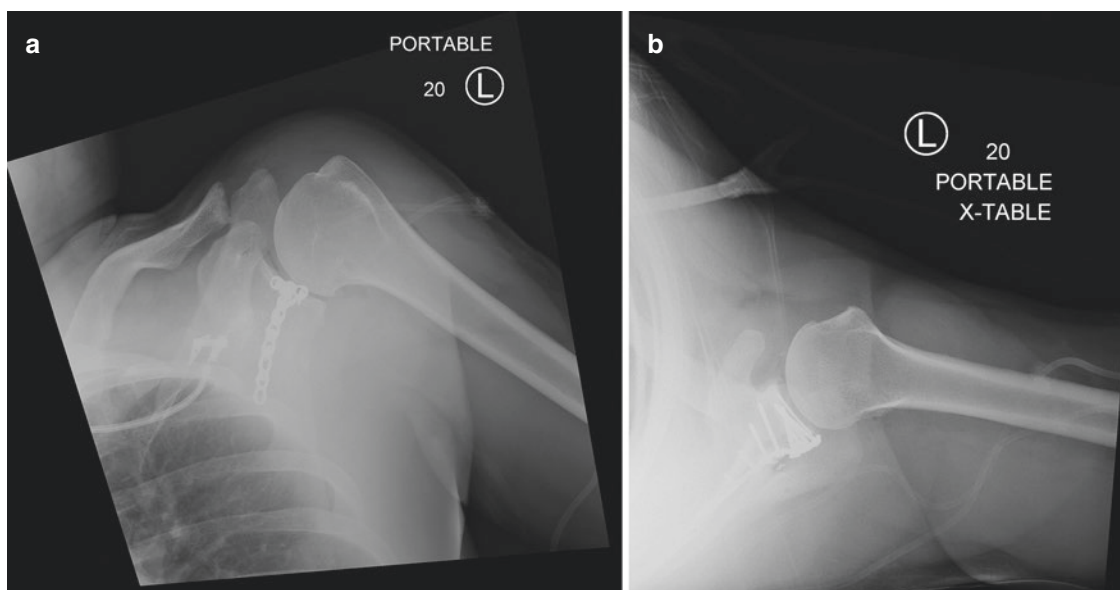
**Fig. 7.73** Dental pick manipulating posterior glenoid fragment



**Fig. 7.74** Freer in glenohumeral joint; fracture fragment displaced distally, revealing glenoid fracture (*arrow*)

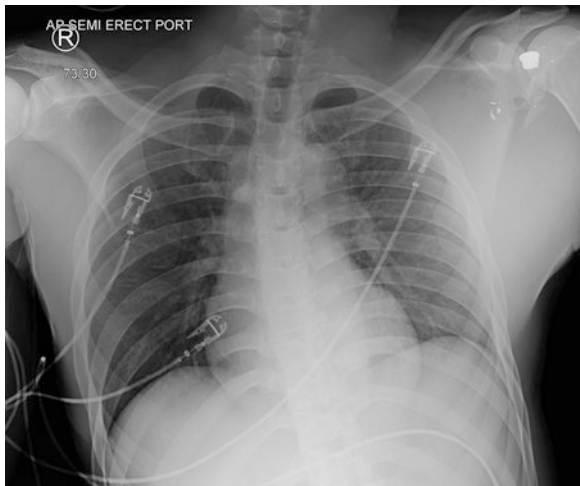


**Fig. 7.75** 24-mm locking T-plate fixation following reduction and provisional K-wire fixation

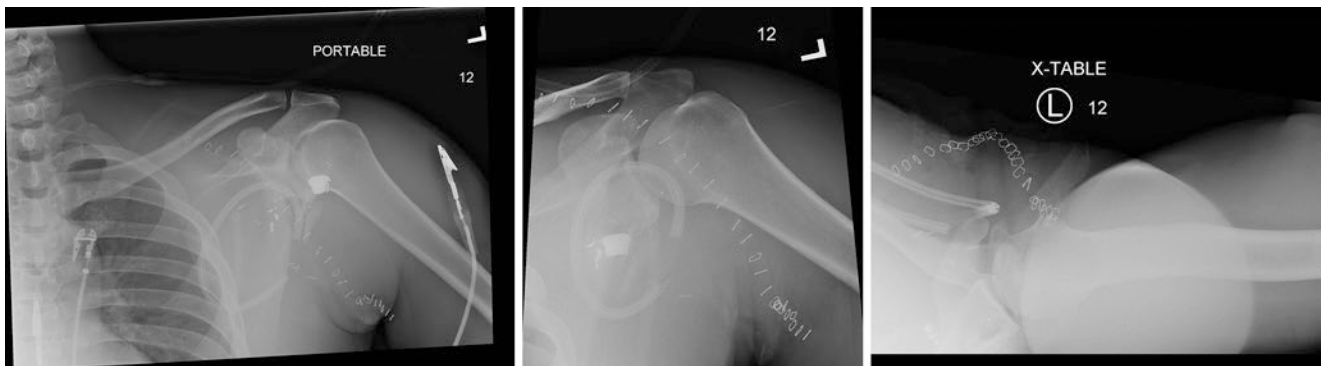


**Fig. 7.76** (a, b) Intraoperative radiographs following ORIF through posterior approach

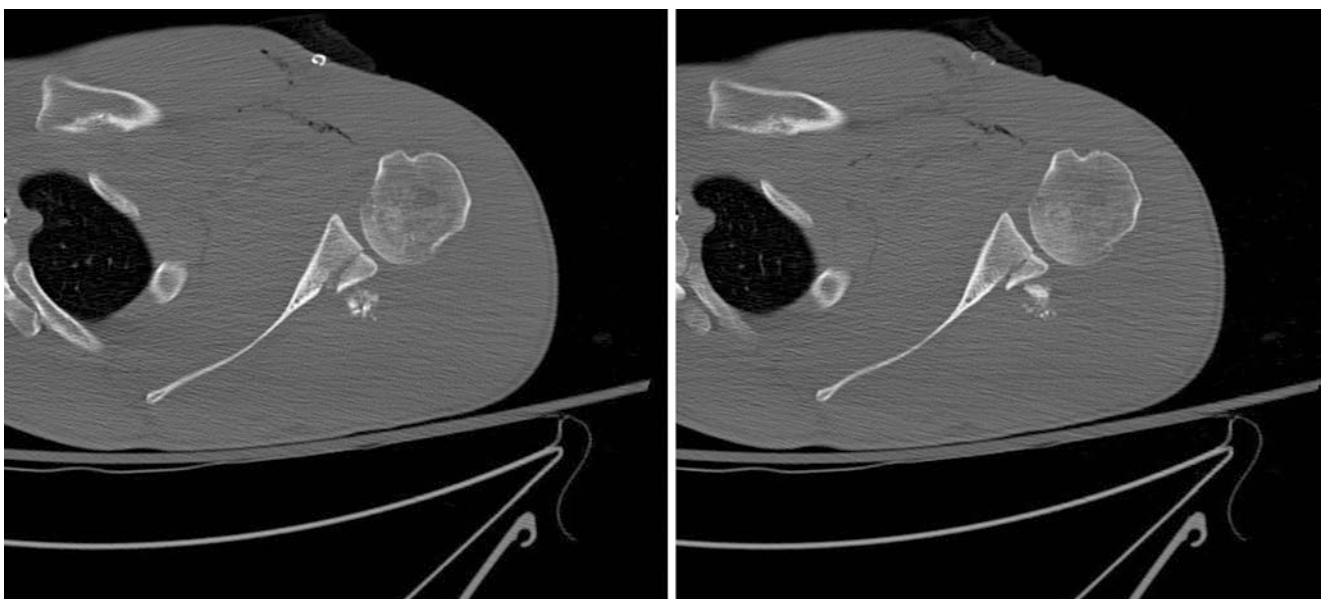




**Fig. 7.77** Chest radiograph demonstrating glenoid fracture and retained metallic foreign body



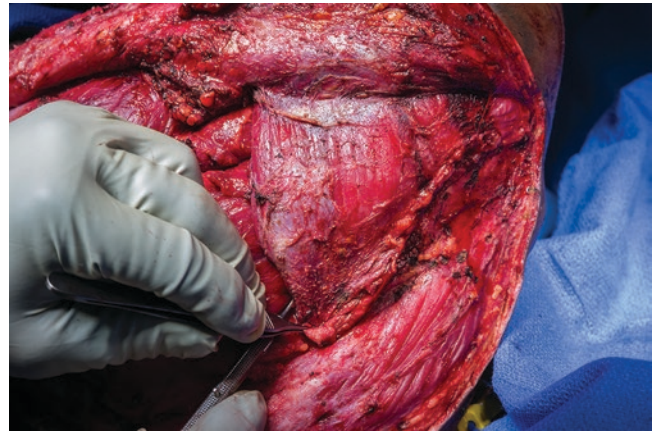
**Fig. 7.78** Shoulder radiography following vascular exploration



**Fig. 7.79** Posterior subluxation of humeral head with posterior glenoid fragment



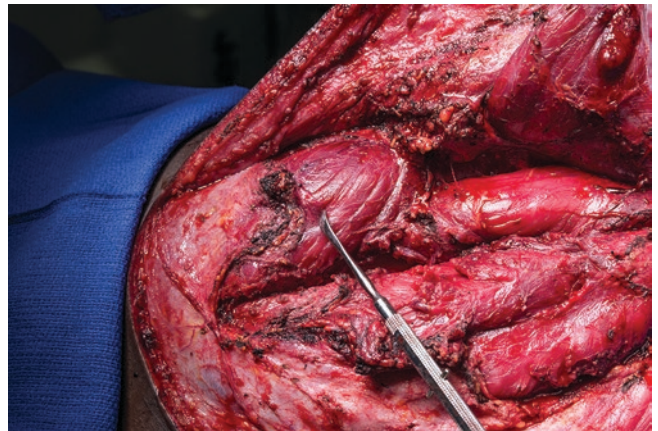
**Fig. 7.80** Clinical example of left glenoid ORIF; incision and skin flap raised



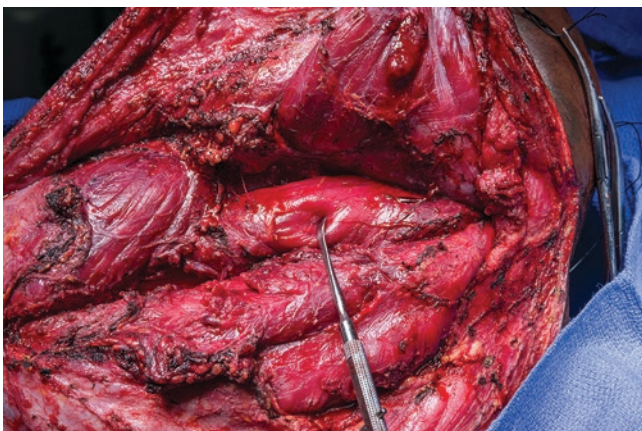
**Fig. 7.81** Deltoid being elevated



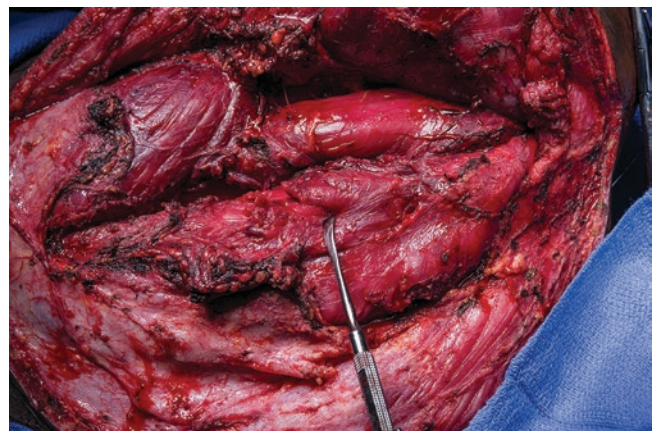
**Fig. 7.82** Deltoid reflected, demonstrating teres major, teres minor, and infraspinatus



**Fig. 7.83** Teres major, probe



**Fig. 7.84** Teres minor, probe

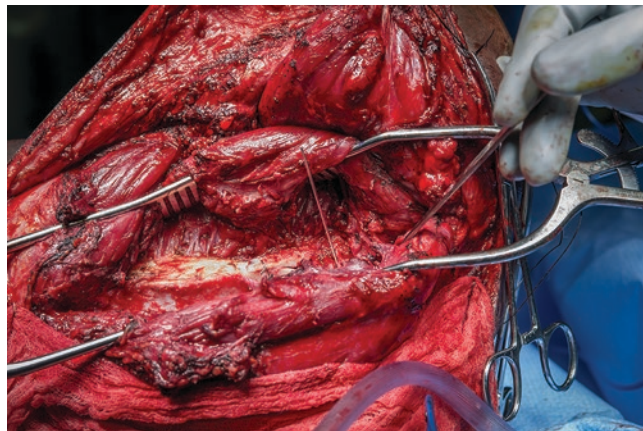


**Fig. 7.85** Infraspinatus, probe





**Fig. 7.86** Deltoid tacked to arm



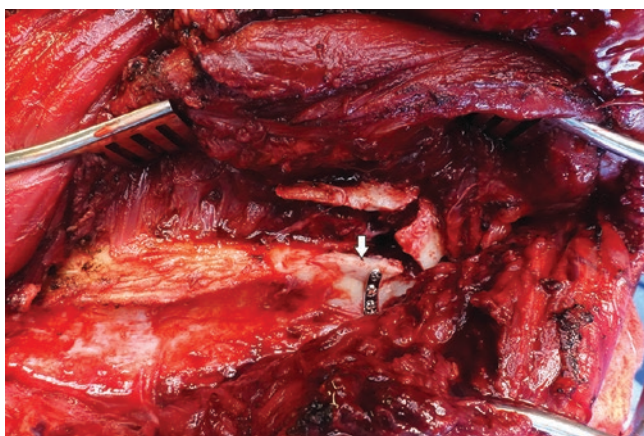
**Fig. 7.87** Retractors in teres minor, infraspinatus interval



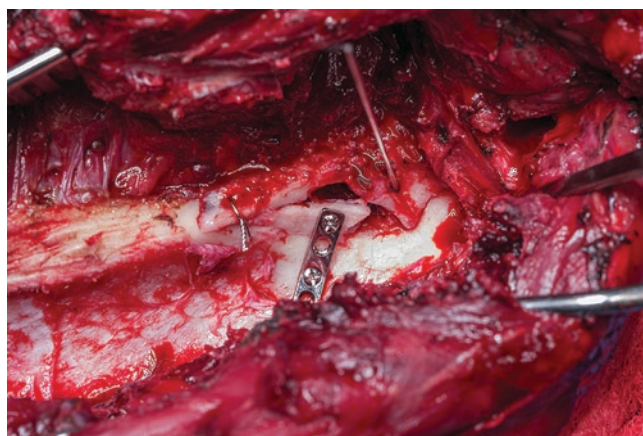
**Fig. 7.88** Lateral border fragment predrilled in preparation for K-wire insertion (to prevent K-wire “cooking” fragment)



**Fig. 7.89** Lateral border fragment predrilled in preparation for K-wire insertion (to prevent K-wire “cooking” fragment)

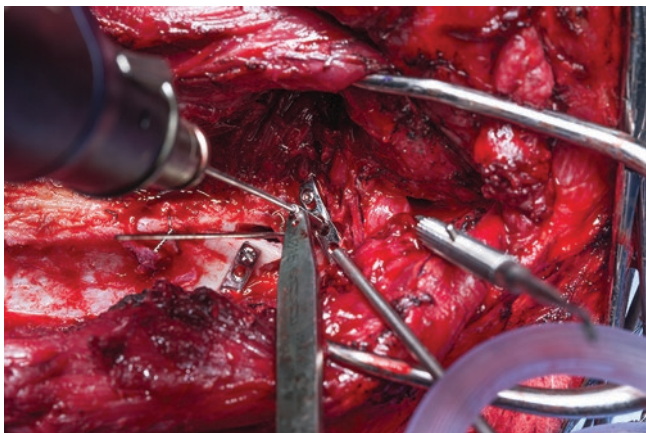


**Fig. 7.90** Fragment in place held with K-wire cut flush (arrow), then mini plate

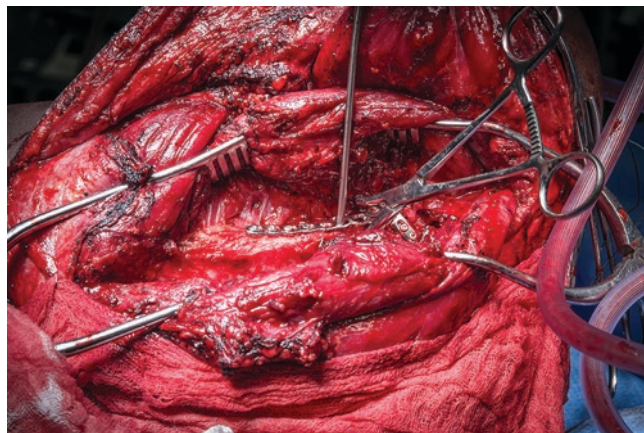


**Fig. 7.91** Provisional fixation in place with interosseous wires, K-wire, and mini plate





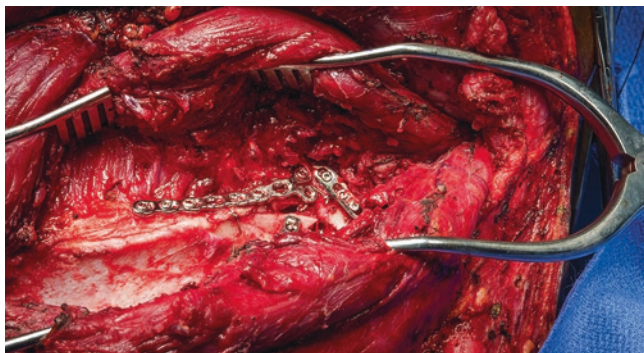
**Fig. 7.92** Mini-fragment 2.0-mm plate for articular fragment fixation; Freer in joint space for reference in shooting screws



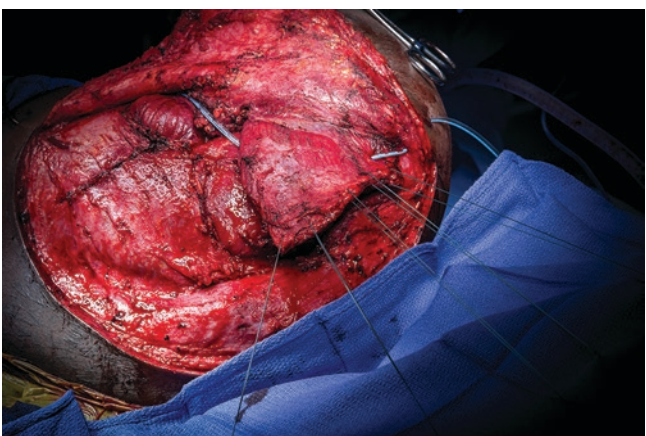
**Fig. 7.93** Lateral-border 2.4-mm locking T plate in place



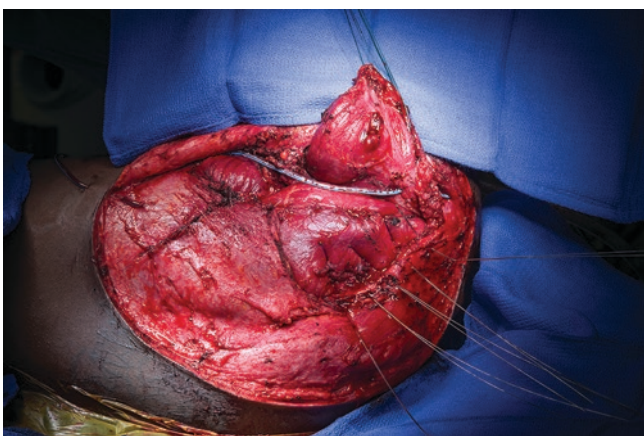
**Fig. 7.94** Checking joint for screw penetration



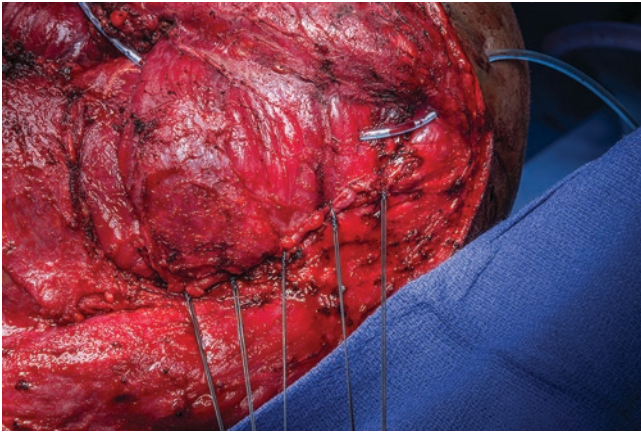
**Fig. 7.95** Final plate fixation



**Fig. 7.96** Sutures in deltoid in preparation for reinsertion



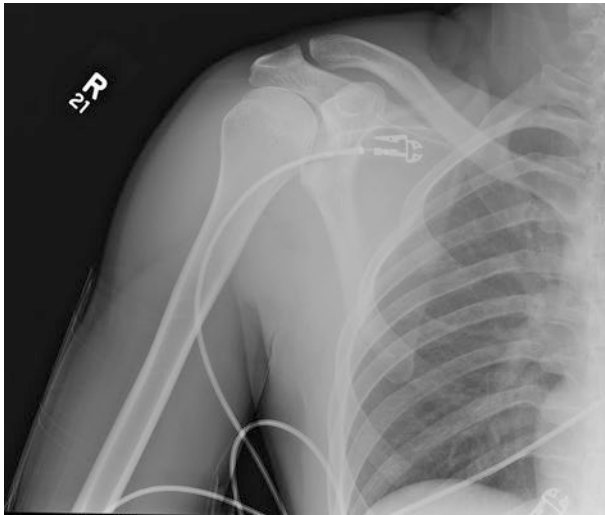
**Fig. 7.97** 24-gauge wires through scapular spine at suture passers



**Fig. 7.98** #2 Ethibond® sutures tied

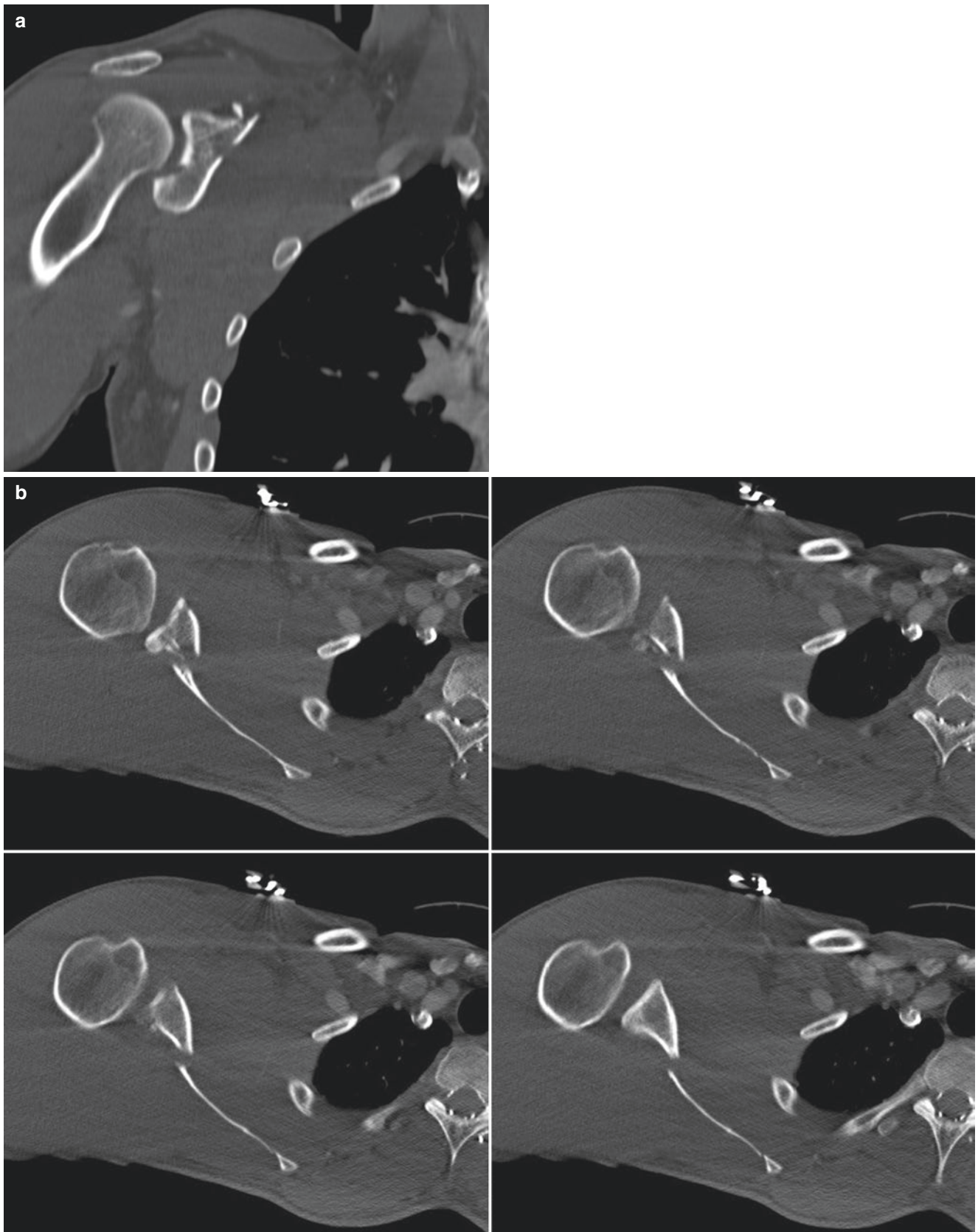


**Fig. 7.99** Radiographs following ORIF



**Fig. 7.100** Shoulder AP radiographs demonstrating glenoid fracture with strategically placed EKG lead





**Fig. 7.101** (a) Intra-articular displacement on CT scan. (b) CT scan sequence demonstrating split in glenoid with transverse step-off





**Fig. 7.102** 3D reconstruction demonstrating intra-articular step-off



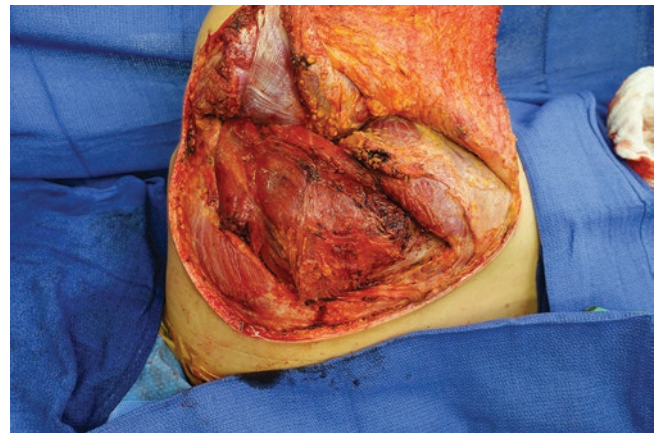
**Fig. 7.103** Clinical example of right glenoid ORIF. Skin incision and flap elevated



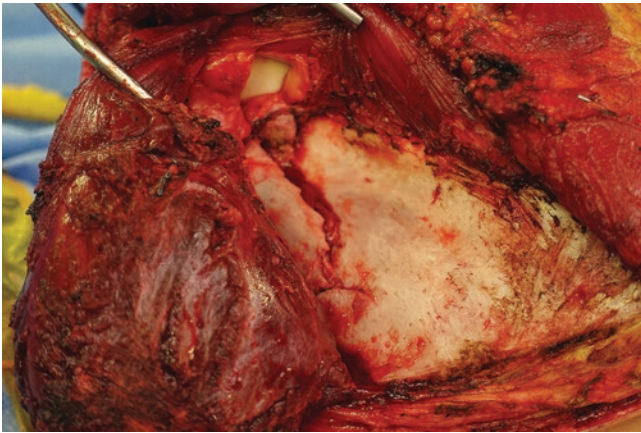
**Fig. 7.104** Skin flap retracted



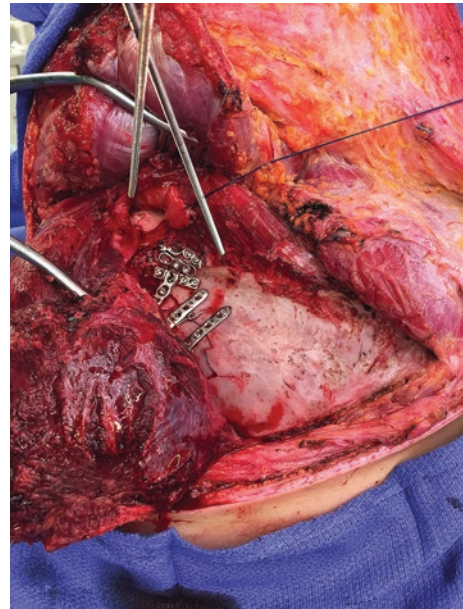
**Fig. 7.105** Deltoid mobilized and interval between infraspinatus and teres minor developed (*arrow*)



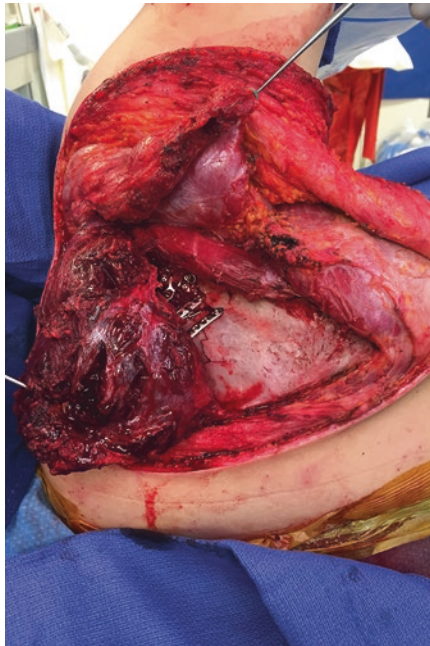
**Fig. 7.106** Deltoid tacked laterally



**Fig. 7.107** Fracture exposed

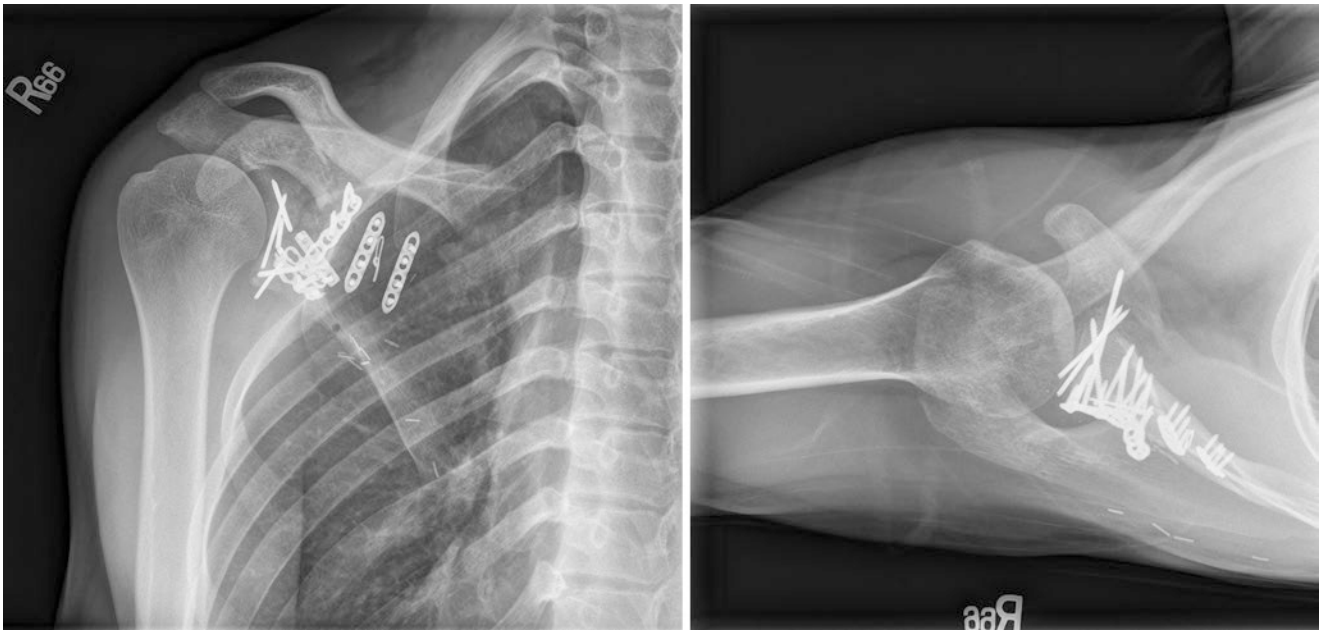


**Fig. 7.108** Threaded Steinmann pins in humeral head and lateral border, used with large lamina spreader for joint visualization



**Fig. 7.109** Final fixation, demonstrating interval between infraspinatus and teres minor





**Fig. 7.110** Final Grashey and axillary radiographs

### 7.5.5 Patient Protocols Following the Procedure

The patient's arm is placed in a sling. I generally prescribe supported Codman's exercises for 2 weeks, followed by passive range of motion for 2 weeks, as I prefer not to have active motion pulling on the deltoid repair. My shoulder

protocol is routine, regardless of the approach or the fractures about the shoulder. Specifically, proximal humerus fractures are treated in a similar fashion, with 2 weeks of supported Codman's exercises, 2 weeks passive, and 2 weeks active, followed by strengthening and weight-bearing at 3 months

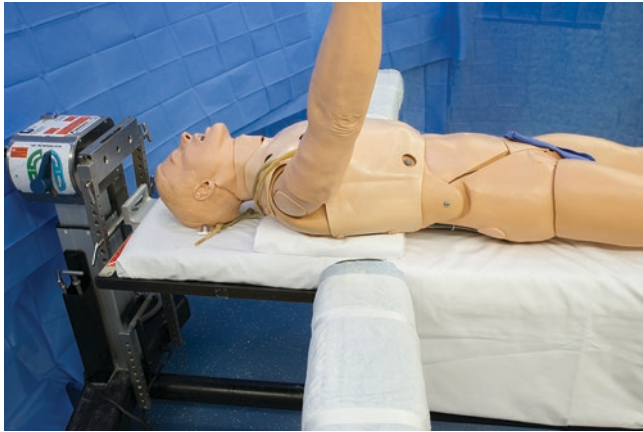


## 7.6 Anterior Operative Approach to the Glenoid

The anterior approach to the glenoid is the deltopectoral approach. I use this approach exclusively, acknowledging that other approaches have been described, including from

superior or cephalad [21]. My concern about some of these other approaches is the ability to extend the surgical incision to do subsequent reconstructive procedures.

The patient is positioned on a radiolucent table with a folded two-sheet bump behind the shoulder (Figs. 7.111 and 7.112).



**Fig. 7.111** Supine position on carbon fiber radiolucent table with two-sheet bump on arm board below elbow to allow C-arm clearance



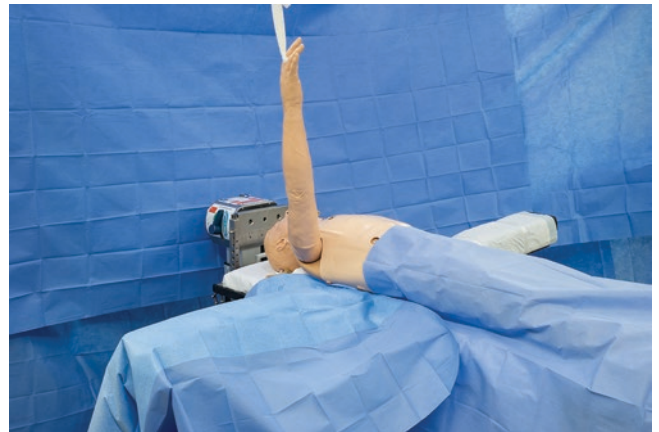
**Fig. 7.112** Use an arm board with a special clip, not a metal clamp, so as not to block C-arm shots

The C-arm comes from the opposite side, in a right angle in the axilla. I use a radiolucent arm board as opposed to a hand table. The forequarter from the ear to the chin, to the

midline, to the inframammary region is predraped, then final draping ensues (Figs. 7.113, 7.114, 7.115, 7.116, 7.117, 7.118, 7.119, 7.120, and 7.121).



**Fig. 7.113** Body drape



**Fig. 7.114** Three-quarter drape on arm board



**Fig. 7.115** Perimeter towels



**Fig. 7.116** Perimeter towels



**Fig. 7.117** Split drape with tails down



**Fig. 7.118** Split drape with tails up

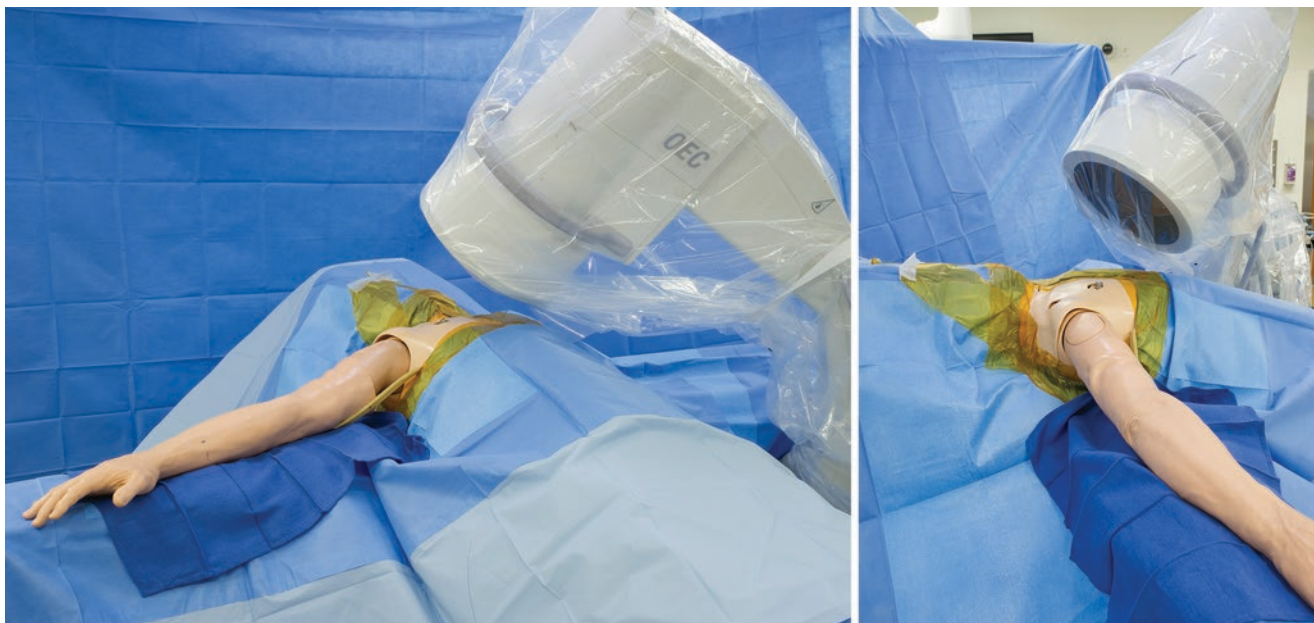


**Fig. 7.119** Ioban® around perimeter



**Fig. 7.120** Hand down, fingers painted





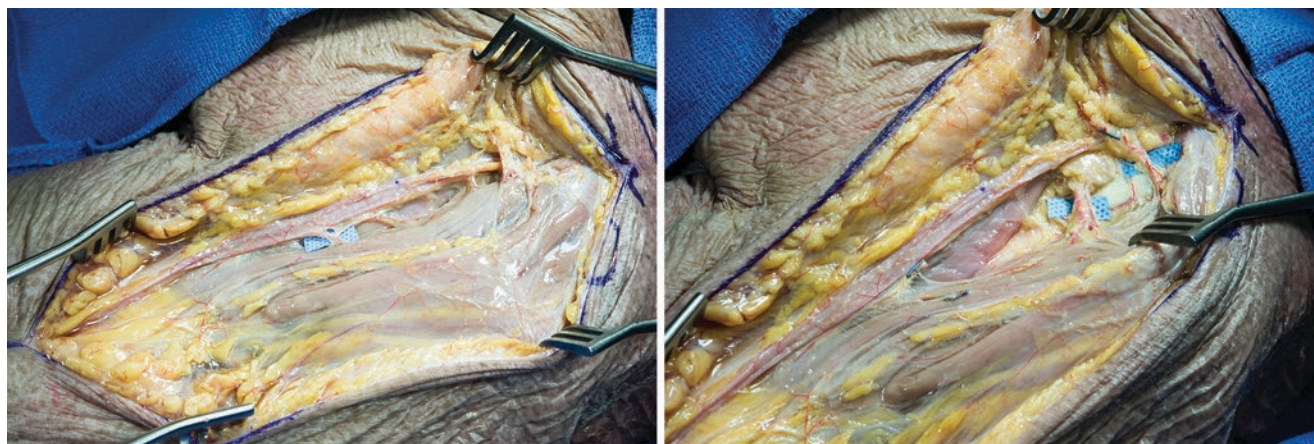
**Fig. 7.121** Patient with head up, C-arm positioned

The surgical incision is from the clavicle to the deltoid insertion (Fig. 7.122).



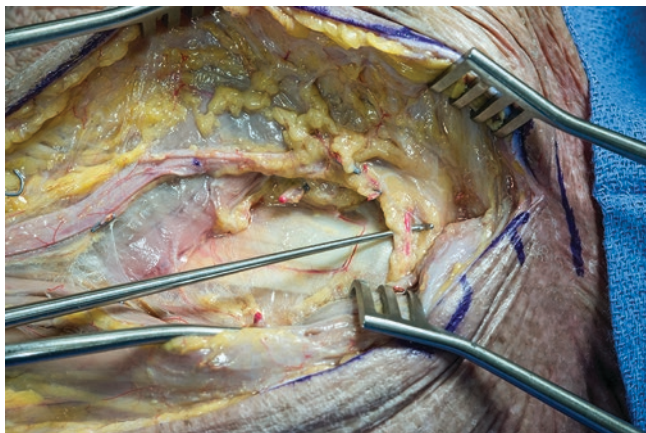
**Fig. 7.122** Anterior deltopectoral approach incision (*bracketed by arrows*), left shoulder

Once the incision is performed, the cephalic vein is visualized. If the vein is difficult to visualize, the fat pad over the coracoid can be visualized and used as a guide to develop the deltopectoral interval. I maintain the cephalic vein medially, using Ligaclips® to divide the branches coursing into the deltoid (Figs. 7.123 and 7.124).



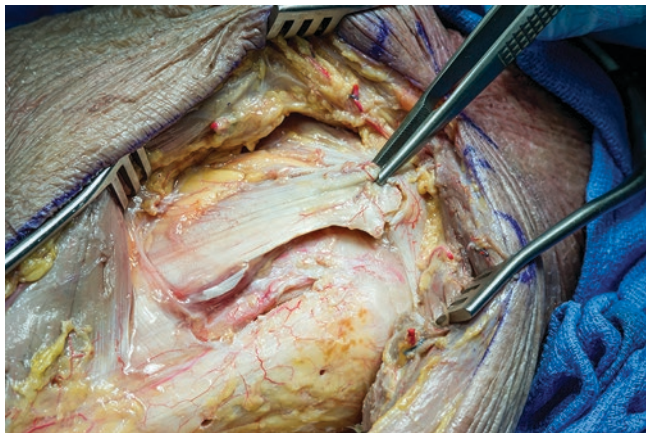
**Fig. 7.123** Cephalic vein with tributaries from deltoid





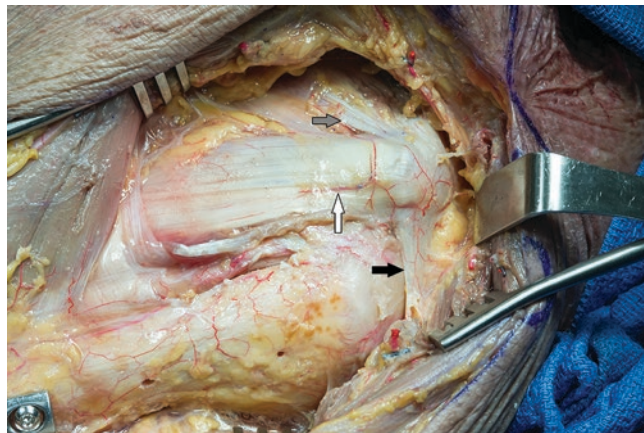
**Fig. 7.124** Branches from thoracoacromial arch

Invariably, a coracoid osteotomy is required. I perform a V-chevron osteotomy of the coracoid with only the attachment of the conjoint tendon attached to the osteotomized fragment (Fig. 7.126).



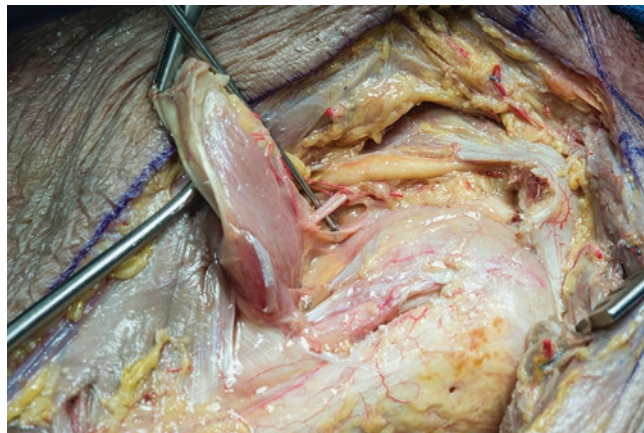
**Fig. 7.126** Coracoid V-chevron osteotomy

This prevents tensioning or traction of the vein crossing the field, acknowledging the potential for a scenario of venous congestion of the deltoid (which I've never been aware of occurring). The CA ligament, pectoralis minor, and conjoint tendon are identified (Fig. 7.125).



**Fig. 7.125** Coracoacromial (CA) ligament (*black arrow*), conjoint tendon (*white arrow*), pectoralis minor (*grey arrow*)

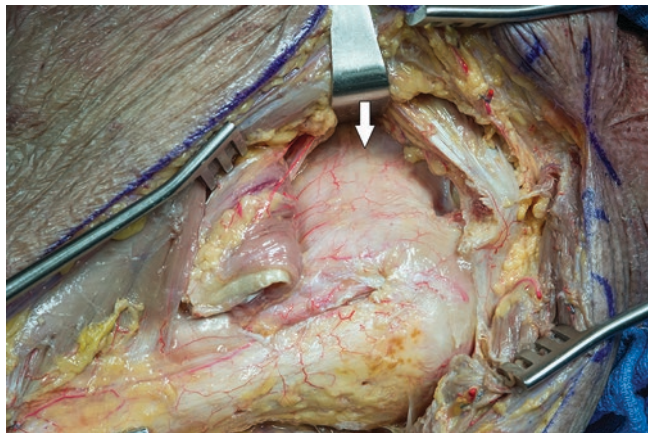
I have abandoned predrilling the coracoid because I have found it difficult to find the predrilled holes. The subsequent fixation will use an interosseous wire technique. The conjoint tendon is reflected distally, and I will visualize the lateral cord as well as the musculocutaneous nerve (Fig. 7.127).



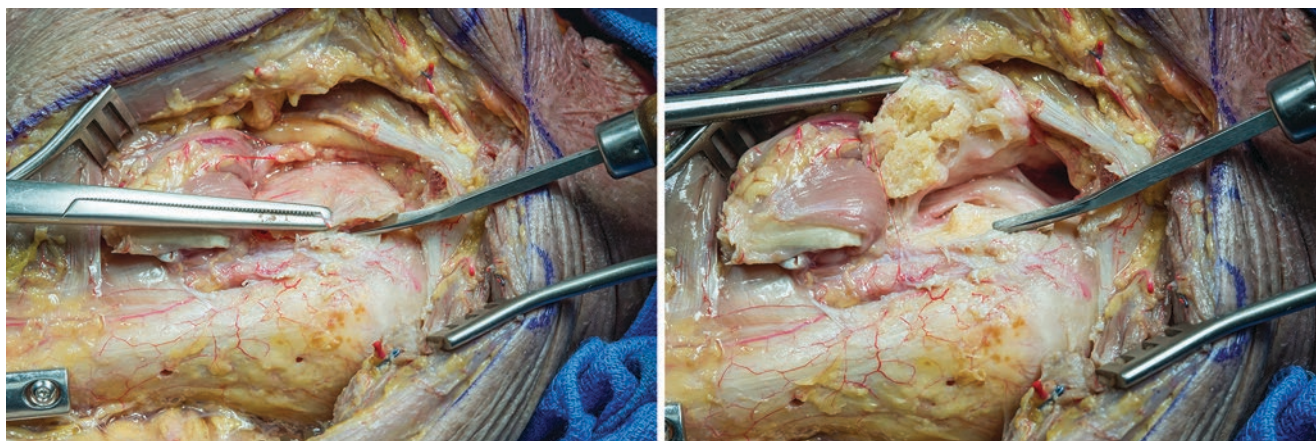
**Fig. 7.127** Coracoid, conjoint tendon, coracobrachialis, and short head of biceps reflected with probe under musculocutaneous nerve

To gain access to the glenoid, I perform a lesser tuberosity osteotomy, without predrilling. I try to preserve the soft-tissue restraining sling over the biceps tendon. The interval is developed between the subscapularis and the glenohumeral

ligament and supraspinatus. I use a sharp gouge to elevate the subscapularis with a small portion of the lesser tuberosity to allow bone healing after reinsertion (Figs. 7.128 and 7.129).



**Fig. 7.128** Subscapularis exposed (*arrow*)

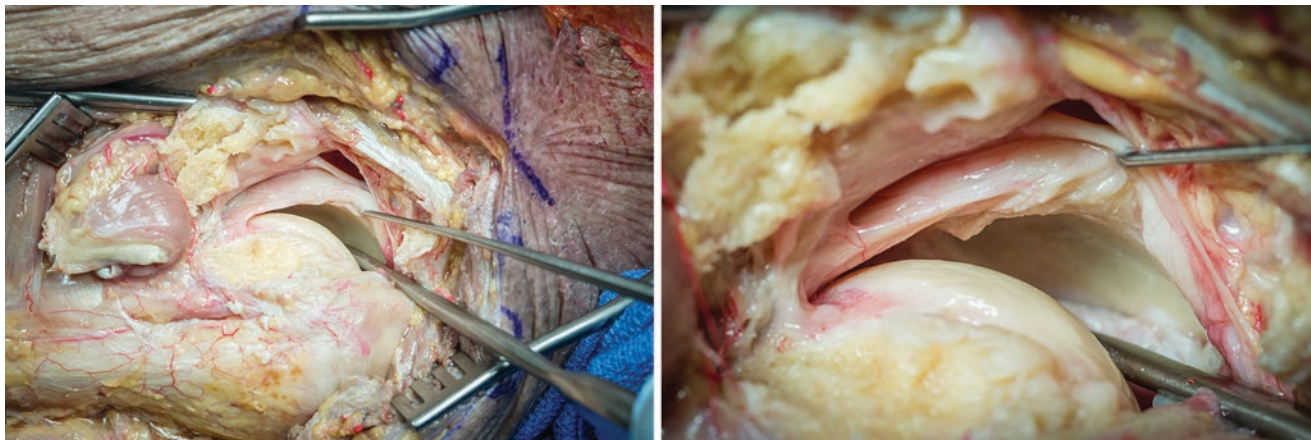


**Fig. 7.129** Lesser tuberosity, osteotomized with a curved gouge



The subscapularis and lesser tuberosity fragment are reflected medially. I find it very difficult to develop a plane between the capsule and the subscapularis, so once the lesser tuberosity is reflected, the joint is exposed (Fig. 7.130).

With the subscapularis reflected, I use a Fakuta retractor to depress the humeral head.



**Fig. 7.130** Anterior glenohumeral joint exposed

### 7.6.1 Issues Relative to Anterior Glenoid Fixation

As I point out to the residents, there are three issues relative to the anterior glenoid fixation. The first is the complexity of the approach, the second is the difficulty in reduction, and the third is performing the fixation. I halfheartedly comment that the easiest approach is transcardiac, particularly on the left shoulder. The orientation of the glenoid fracture can be deceiving; on a CT scan, reducing the fracture and putting in

a screw appears to be a simple process, but this process can be much more difficult than it appears because the projection required to shoot the screws is blocked by the soft tissues of the chest wall.

The fracture fragment—if it is a single fragment—is manipulated with a series of dental picks and hemostats. Once the fracture has been reduced, a series of Kirschner wires (K-wires) are placed. The use of terminally threaded guide wires can allow the use of cannulated, headless screws. I frequently use the Synthes® 2.4–3.0 headless system (Fig. 7.131).

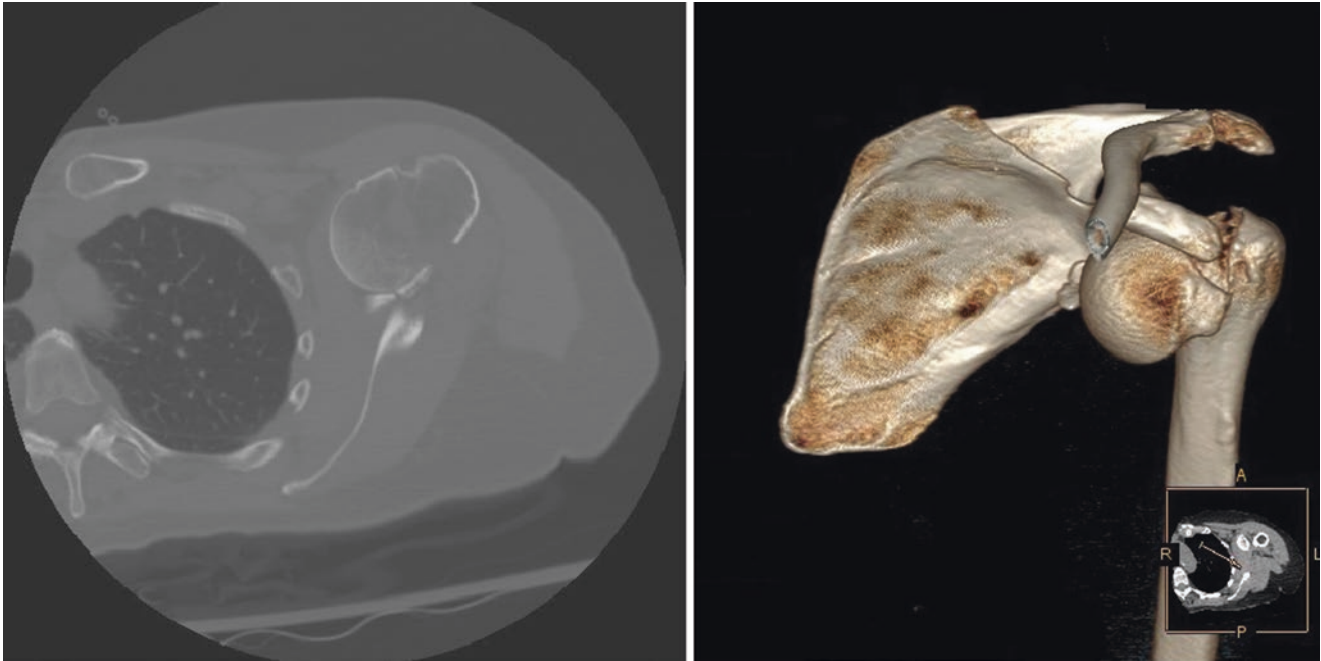


**Fig. 7.131** Radiographs of anterior glenoid fixation with headless screws

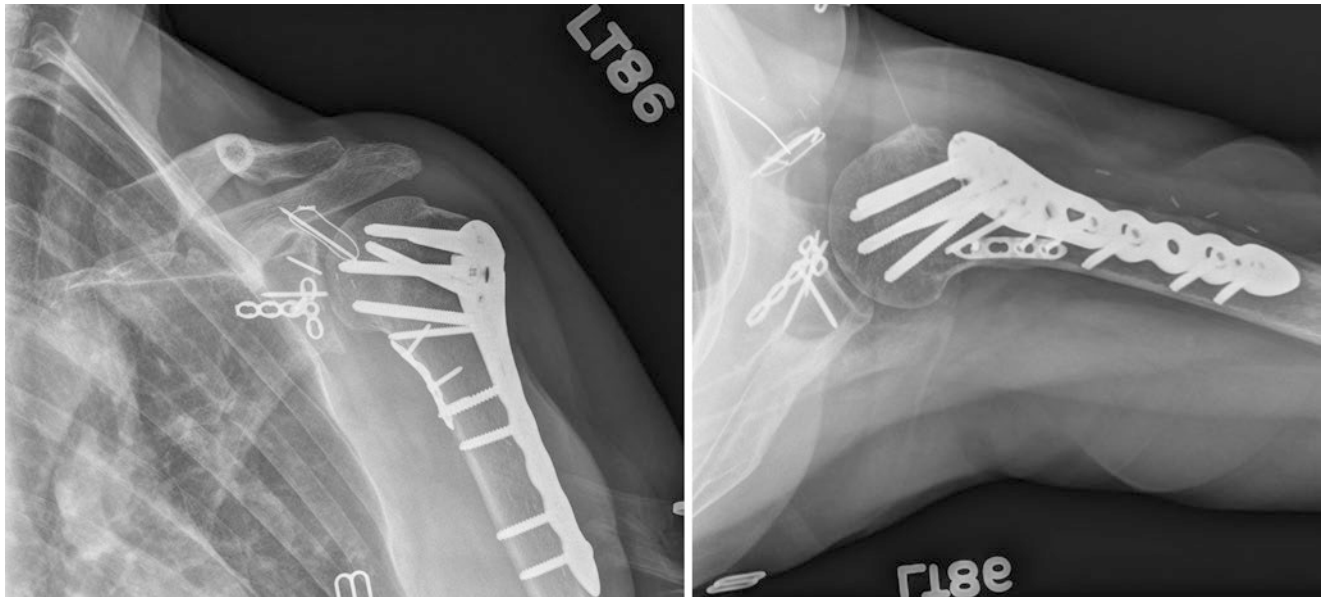


Occasionally I will use threaded Steinmann pins for a fixation, with the pins cut and then burred, instead of trying to manipulate the fragment too many times. The fragment is usually rather small, but it is critically important because of the inferior glenohumeral ligament attachment and its

subsequent impact on stability. Very rarely, a buttress plate can be placed on the anterior aspect of the scapular body, but it is very difficult to do so because of the slope and the orientation of the screws (Figs. 7.132 and 7.133).



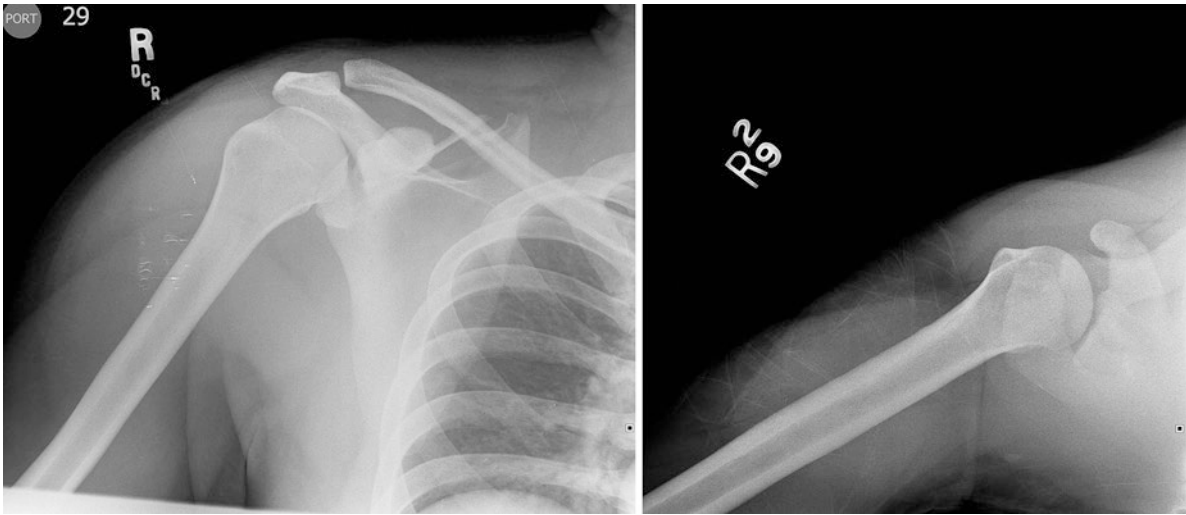
**Fig. 7.132** CT scan and 3D reconstruction of left shoulder anterior fracture dislocation with humeral head and anterior glenoid fracture



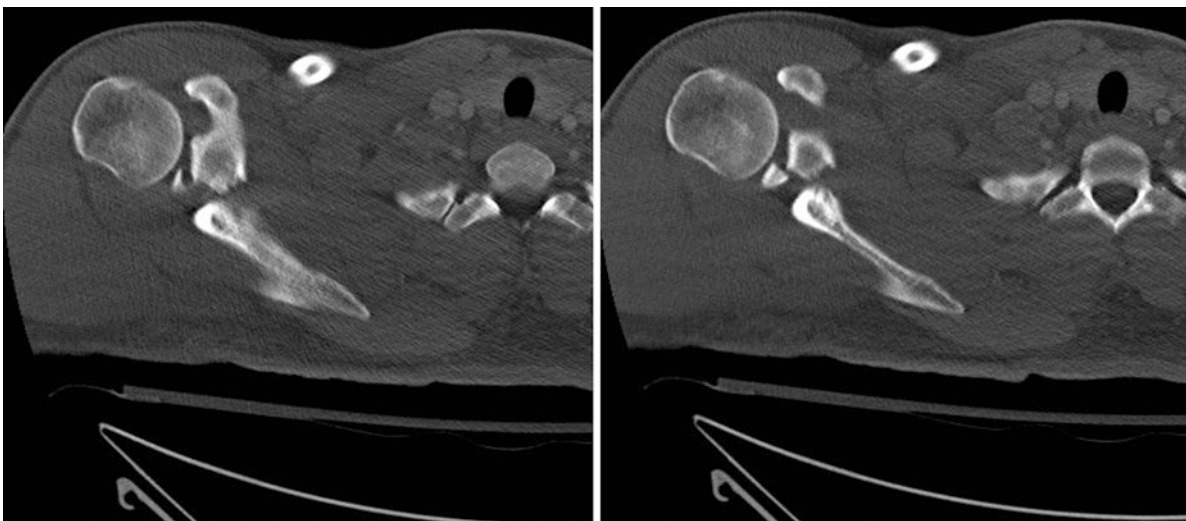
**Fig. 7.133** Radiographs following ORIF via coracoid and lesser tuberosity osteotomies, and fixation with an anterior glenoid buttress plate. The patient did develop avascular necrosis and glenohumeral collapse years after fixation

On occasion, the coracoid process and the anterior fragment are one fragment. This makes the reduction somewhat

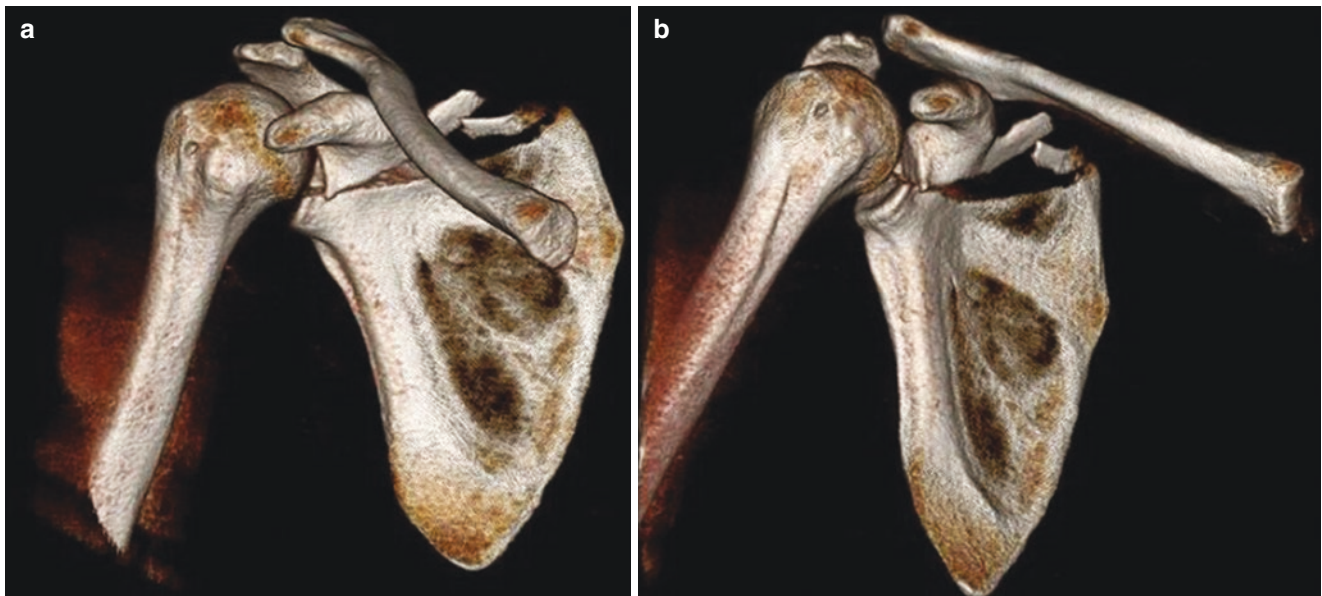
easier, allowing for manipulation of the coracoid and improved screw purchase (Figs. 7.134, 7.135, 7.136, 7.137, and 7.138).



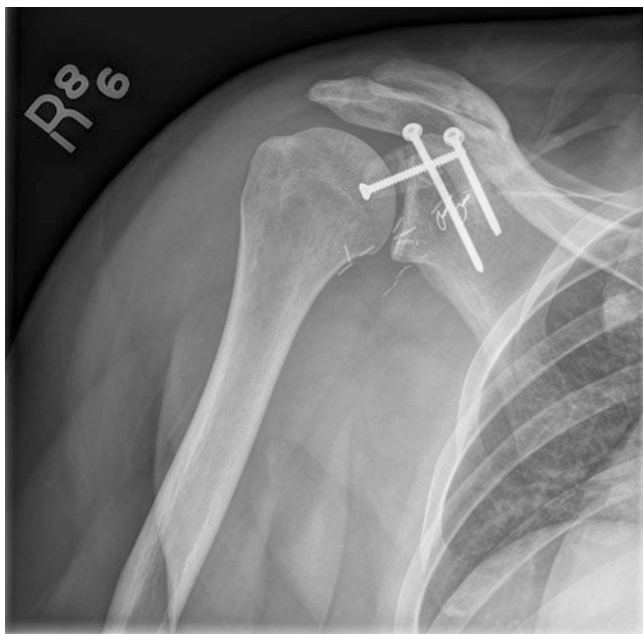
**Fig. 7.134** Radiographs of right glenoid fracture with coracoid and anterior glenoid as one fragment



**Fig. 7.135** CT scan of right glenoid



**Fig. 7.136** (a, b) 3D CT scans of the right glenoid



**Fig. 7.137** Grashey view of right glenoid following ORIF via coracoid osteotomy

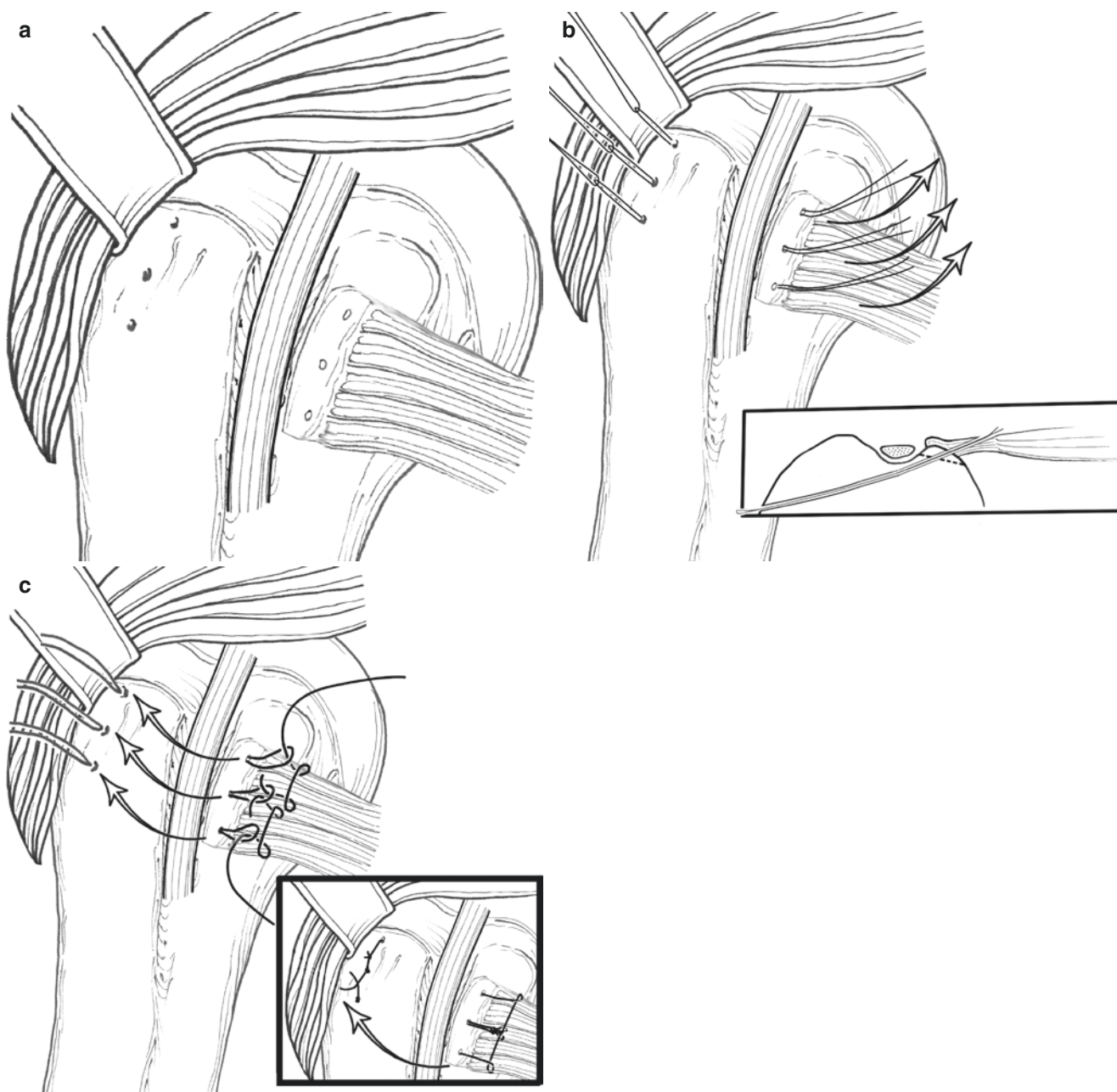


**Fig. 7.138** Axillary view following ORIF



Efforts are made to preserve the labrum. Once the fixation is completed, it is critical to evaluate the glenoid on the axillary as well as the Grashey view. The axillary view is obtained using hard copy because of the difficulty in C-arm positioning.

The subscapularis and lesser tuberosity fragment are reduced and held with a tenaculum; three holes are drilled anteromedially to posterolaterally; #5 Ethibond® will be used for fixation. I place 24-gauge interosseous wires in loop fashion from anterior to posterior and then reverse this to capture and deliver the sutures (Fig. 7.139).



**Fig. 7.139** (a) Holes drilled from medial to lateral with 2.5-mm drill bit through the lesser tuberosity, exiting laterally and coursing beneath the bicipital groove. (b) Looped 24-gauge wire passed from medial to lateral because of difficulty in passing lateral to medial first. Second set

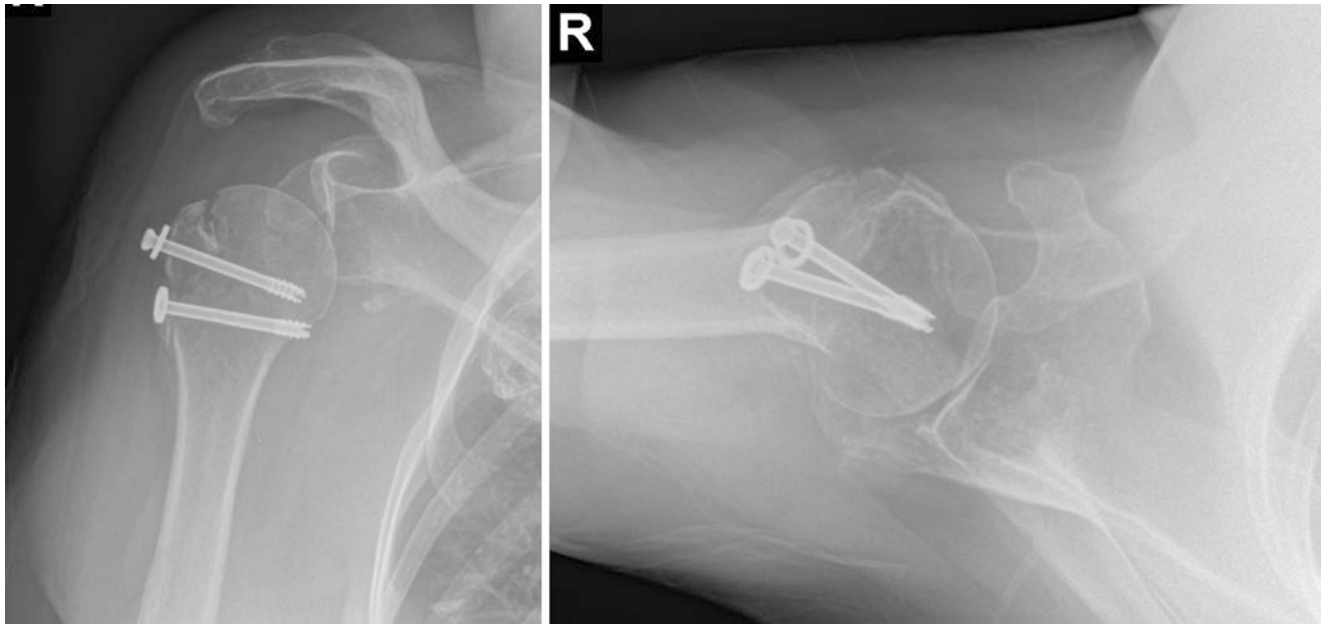
of wires then looped through first set of wires and delivered medially. Locking sutures then passed medial to lateral. (c) Sutures tied laterally over bone bridges. Note two sutures in the middle hole

A suture passer also may be used. I frequently mark one Ethibond® suture with a marking pen to prevent tying the wrong two ends together, as the two limbs of the two sutures go through the same hole. Another trick is to use one Ethibond® suture and one TiCron™ suture, as these are different colors.

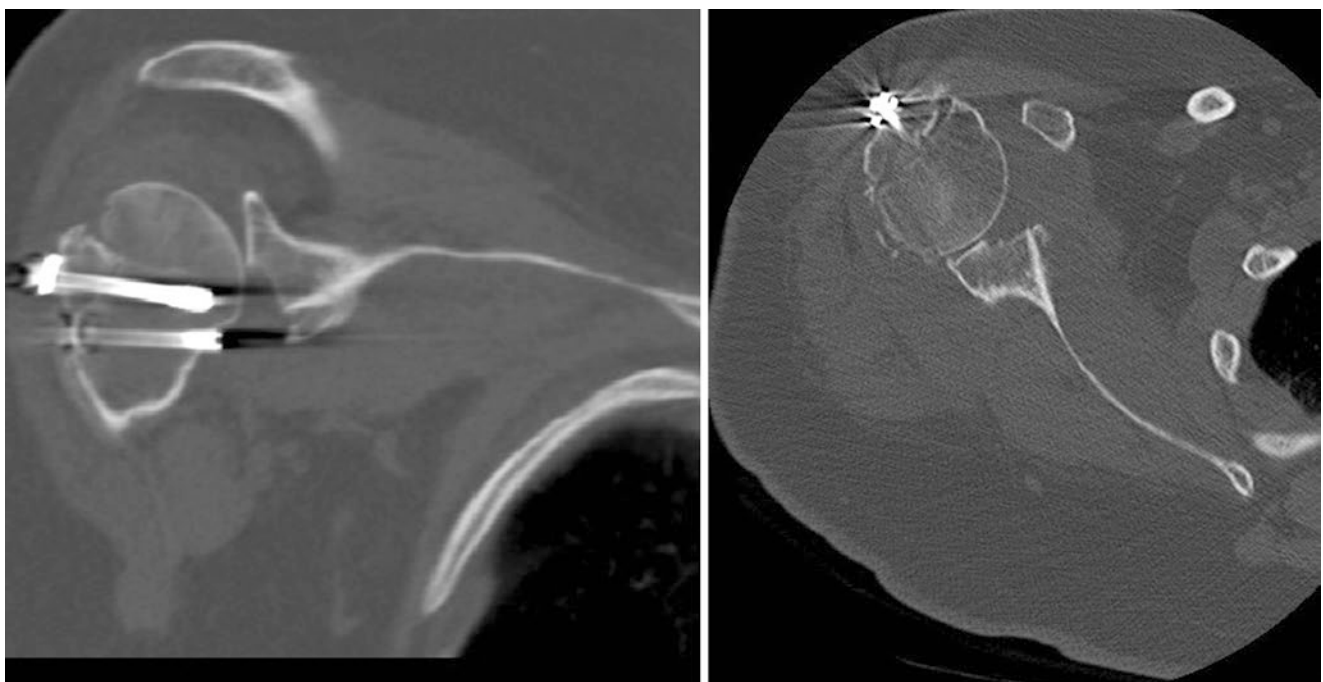
Once the subscapularis and lesser tuberosity are back in place, the conjoint tendon fragment is reduced with a tenaculum. I then place a 0.045-in. K-wire in the center of the fragment, followed by drilling with a 1.5-mm drill bit and passage of a 20- or 22-gauge interosseous wire, depending on the size of

the fragment. I use a three-hole 1.5 mini-fragment plate, with the K-wire being in the center hole. I try to turn the wire to capture the plate, with the wire tightening on the superior side of the coracoid process. The deltopectoral interval is then closed by running a Vicryl suture or an absorbable 2-0 polydioxanone® (PDS) suture. Skin closure is over a medium Hemovac drain.

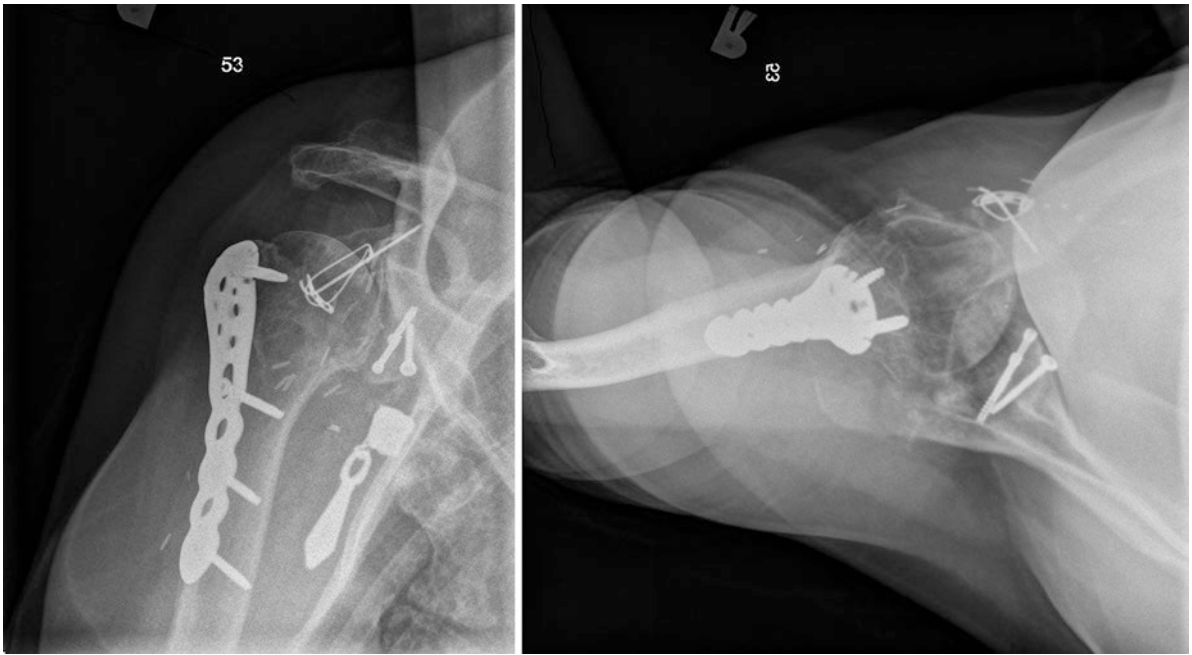
### 7.6.2 Clinical Examples (Figs. 7.140, 7.141, 7.142, 7.143, 7.144, 7.145, 7.146, 7.147, 7.148, and 7.149)



**Fig. 7.140** Radiographs of right shoulder on presentation following ORIF of right greater tuberosity fracture with anterior glenohumeral subluxation associated with anterior glenoid fracture



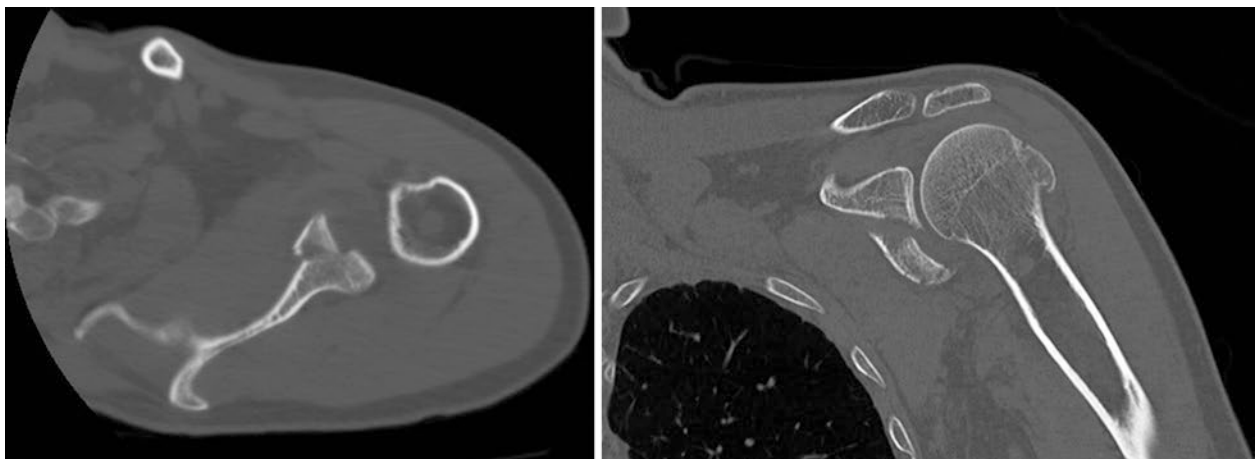
**Fig. 7.141** CT scan reflecting anterior glenoid defect



**Fig. 7.142** Radiographs following ORIF, including anterior glenoid allograft

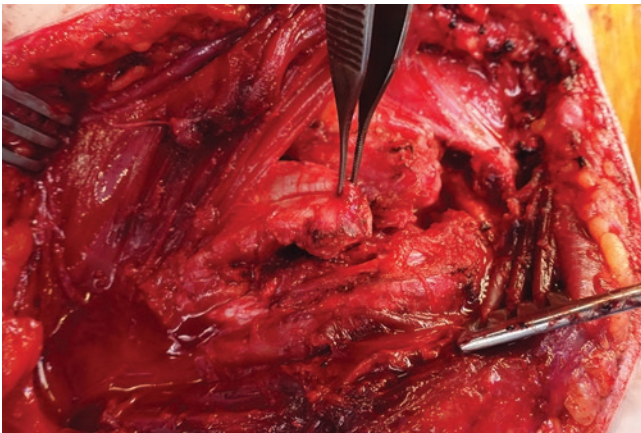


**Fig. 7.143** Injury radiographs of left shoulder with greater tuberosity fracture and anterior glenoid fracture (*arrow*)

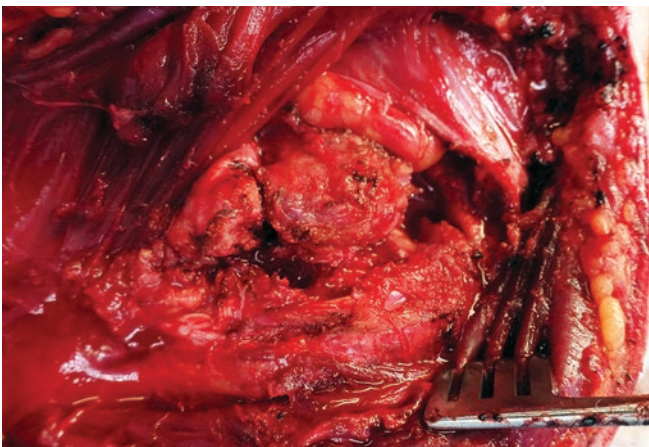


**Fig. 7.144** CT scan demonstrating anterior glenoid fracture

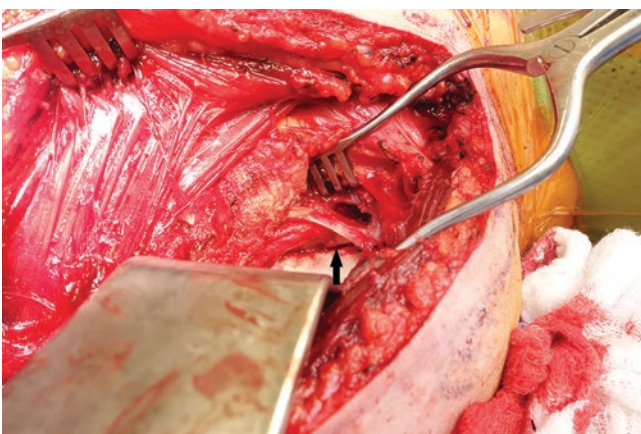
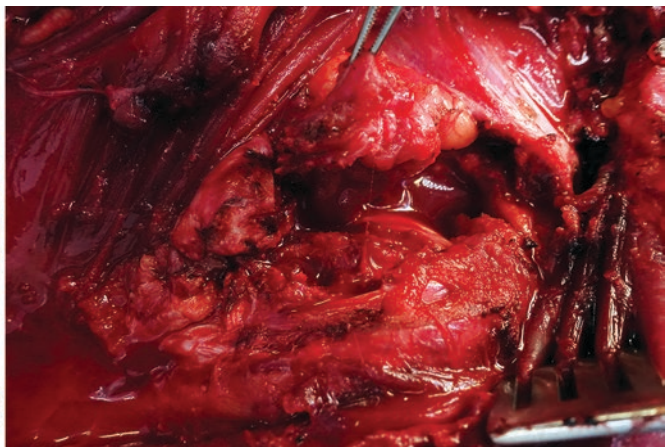




**Fig. 7.145** Coracoid osteotomy for approach to left shoulder



**Fig. 7.146** Lesser tuberosity osteotomy



**Fig. 7.147** Displaced fragment (*arrow*)



**Fig. 7.148** Reduced fragment with fixation in place



**Fig. 7.149** Radiographs following ORIF via an anterior approach

### 7.6.3 Patient Rehabilitation

The rehabilitation program is similar to the program for posterior approaches: 2 weeks of supported Codman's exercises, 2 weeks passive, and 2 weeks active assisted, followed by strengthening. Weight-bearing can begin at 3 months.

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## 8.1 Treatment Options for Floating Shoulder

The combination of clavicle fracture and scapular glenoid neck fracture is commonly known as a *floating shoulder*, denoting that the arm is in discontinuity with the axial skeletal system. As noted with clavicle and scapular fractures, surgical intervention is generally not justified. Potential treatment options for floating shoulder are nonoperative treatment for both fractures, operatively fixing either the clavicle or the scapula, or fixing both. Each of these options has proponents (Table 8.1).

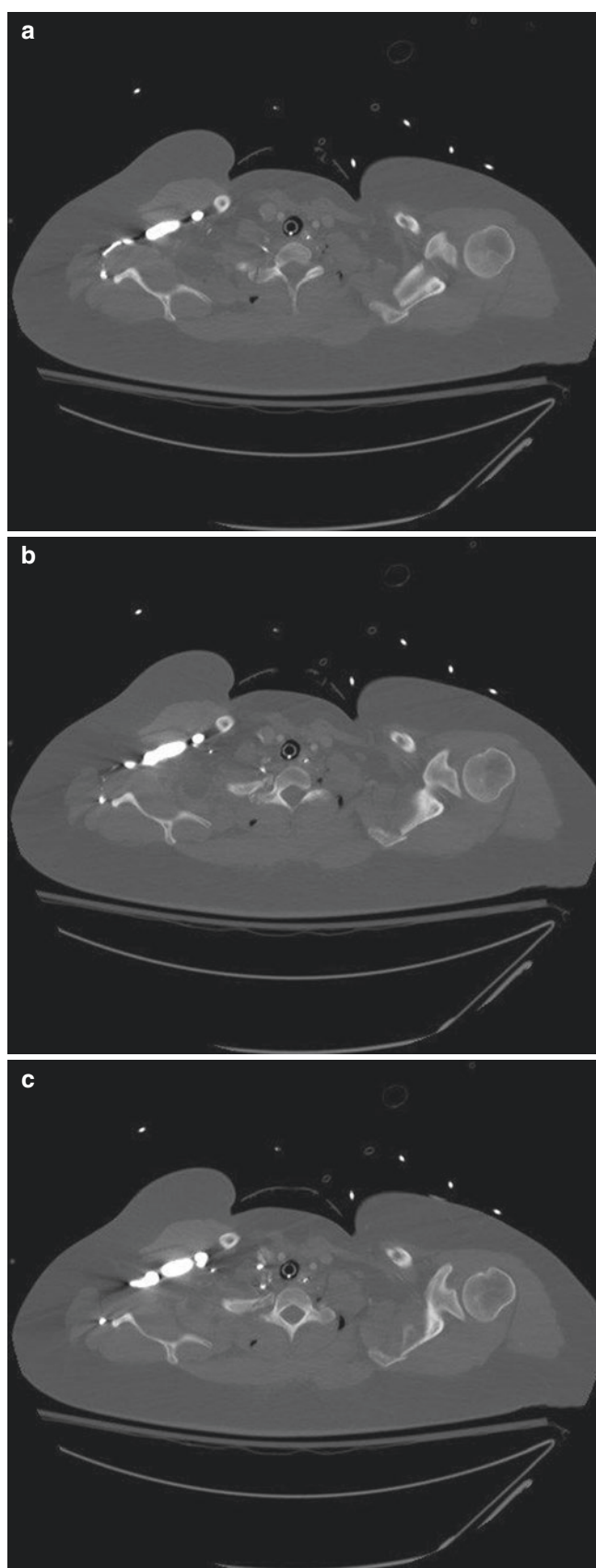
Except in rare circumstances such as associated open clavicle fractures undergoing debridement and fixation, my treatment of choice is nonoperative (Figs. 8.1, 8.2, 8.3, and 8.4).

**Table 8.1** Review of floating shoulder studies

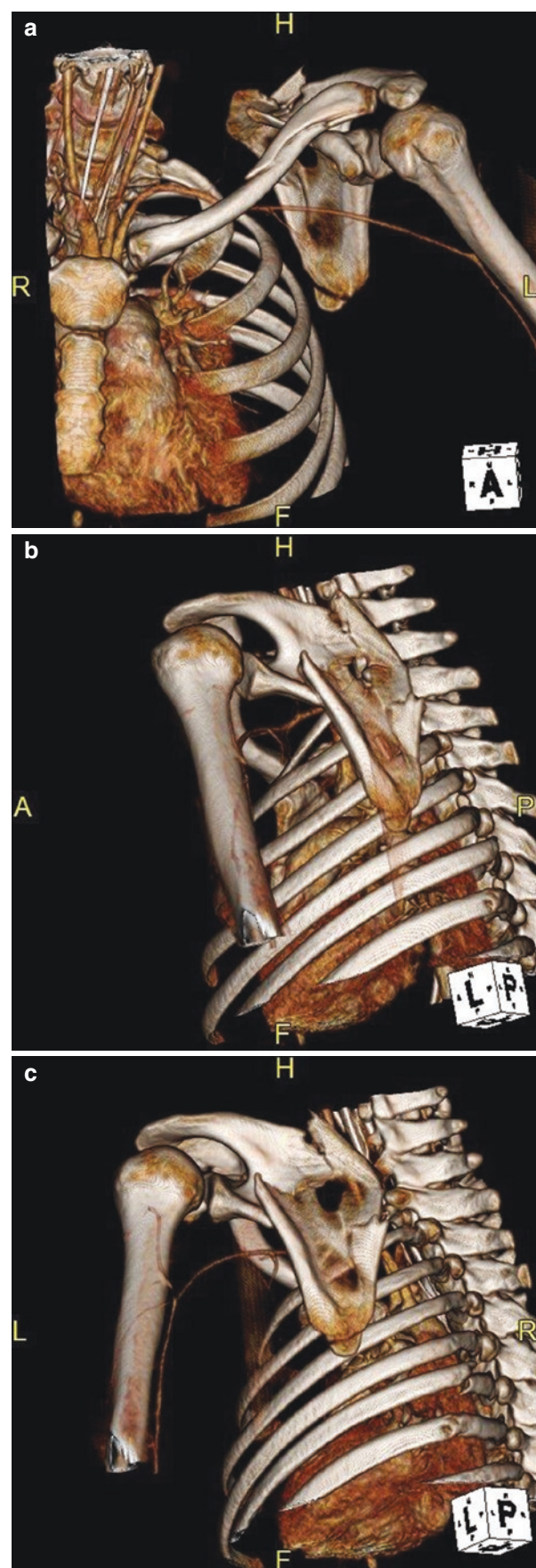
Study	Year	Patients	Findings
Herscovici <i>et al.</i> [1]	1992	11 patients; 9 reviewed	7 ORIF clavicle: excellent 2 nonoperative: good/poor
Ramos <i>et al.</i> [2]	1997	16 nonoperative (no control)	92% good/excellent
Egol <i>et al.</i> [3, 4]	2001	12 nonoperative 7 operative (4 intra-articular glenoid)	Good results both modes
Pasapula <i>et al.</i> [5]	2004	Literature review: floating shoulder	ORIF scapula
Pailhes <i>et al.</i> [6]	2013	24 nonoperative 16 operative	No significant difference Lateral offset had negative impact
Yadov <i>et al.</i> [7]	2013	13 nonoperative 12 operative, clavicle only (Herscovici score better)	Glenopolar angle improved in operative patients No significant correlation between pre/post glenopolar angle and final outcome

ORIF open reduction internal fixation

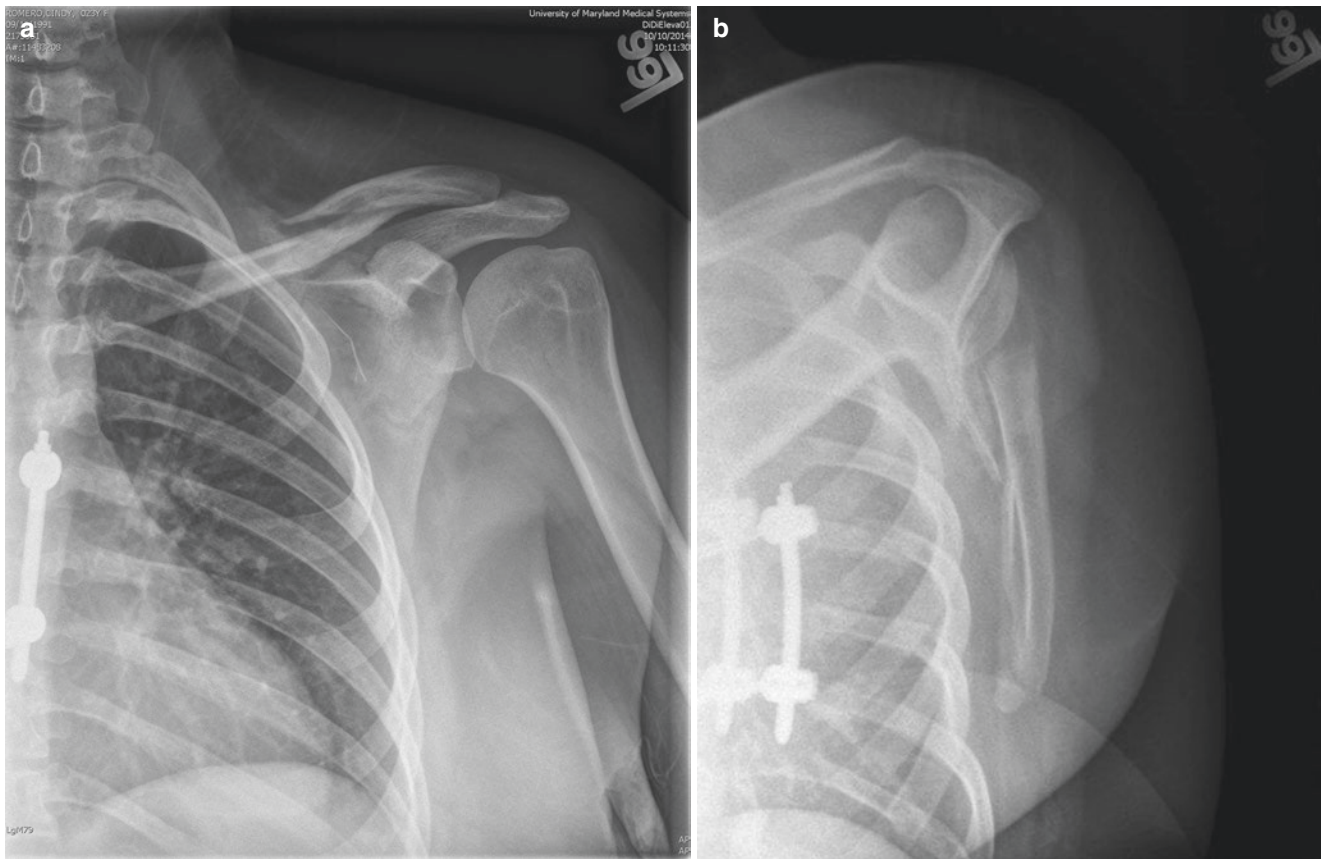




**Fig. 8.1** (a–c) CT scans of patient with floating shoulder treated nonoperatively

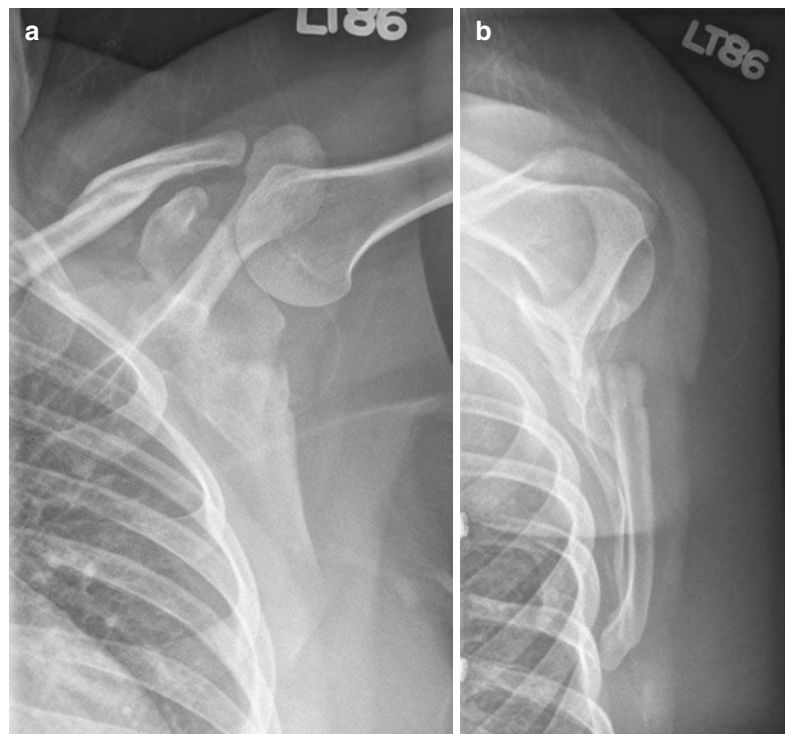


**Fig. 8.2** (a–c) Three-dimensional CT scans of left shoulder



**Fig. 8.3** (a, b) First shoulder radiographs obtained after referral for second opinion. The patient presented with brachial plexus palsy

**Fig. 8.4** (a, b) Follow-up radiographs of healed clavicle and scapula



## 8.2 Exception to Nonoperative Treatment

Disruption of one of the ligamentous components of the superior shoulder suspensory complex, coracoclavicular or acromioclavicular ligaments, with a glenoid neck fracture may also be considered a form of floating shoulder [8]. The initial description of the superior shoulder suspensory complex did not include the coracoacromial ligament [9]. A biomechanical analysis of the floating shoulder was performed, and the results indicated that a scapula glenoid neck fracture and a clavicle fracture did not result in a floating shoulder unless the coracoacromial and acromioclavicular ligaments are divided. Thus, fixation of the scapula and clavicle are not indicated unless the associated ligament injury is identified.

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### 9.1 Overview of Proximal Humeral Fracture Treatment Options

Treatment options for proximal humeral fractures are probably the most varied in the orthopaedic surgeon's armamentarium, ranging from nonoperative treatment to replacement arthroplasty. Fixation options include suturing with either braided sutures or wires, percutaneous Kirschner wire (K-wire), percutaneous plating, percutaneous screws, retrograde or antegrade nails, and open reduction internal fixation (ORIF) [1–16]. The replacement options include hemiarthroplasty, total shoulder arthroplasty, or reverse arthroplasty [17–20].

The treatment selection is frequently driven by age-related criteria. Treatment of the younger patient implies a more anatomically oriented treatment plan, with *younger* frequently defined as anyone the surgeon's age or less. Older patients are more likely to be relegated to conservative treatment or replacement options, with *older* defined as anyone older than the treating physician.

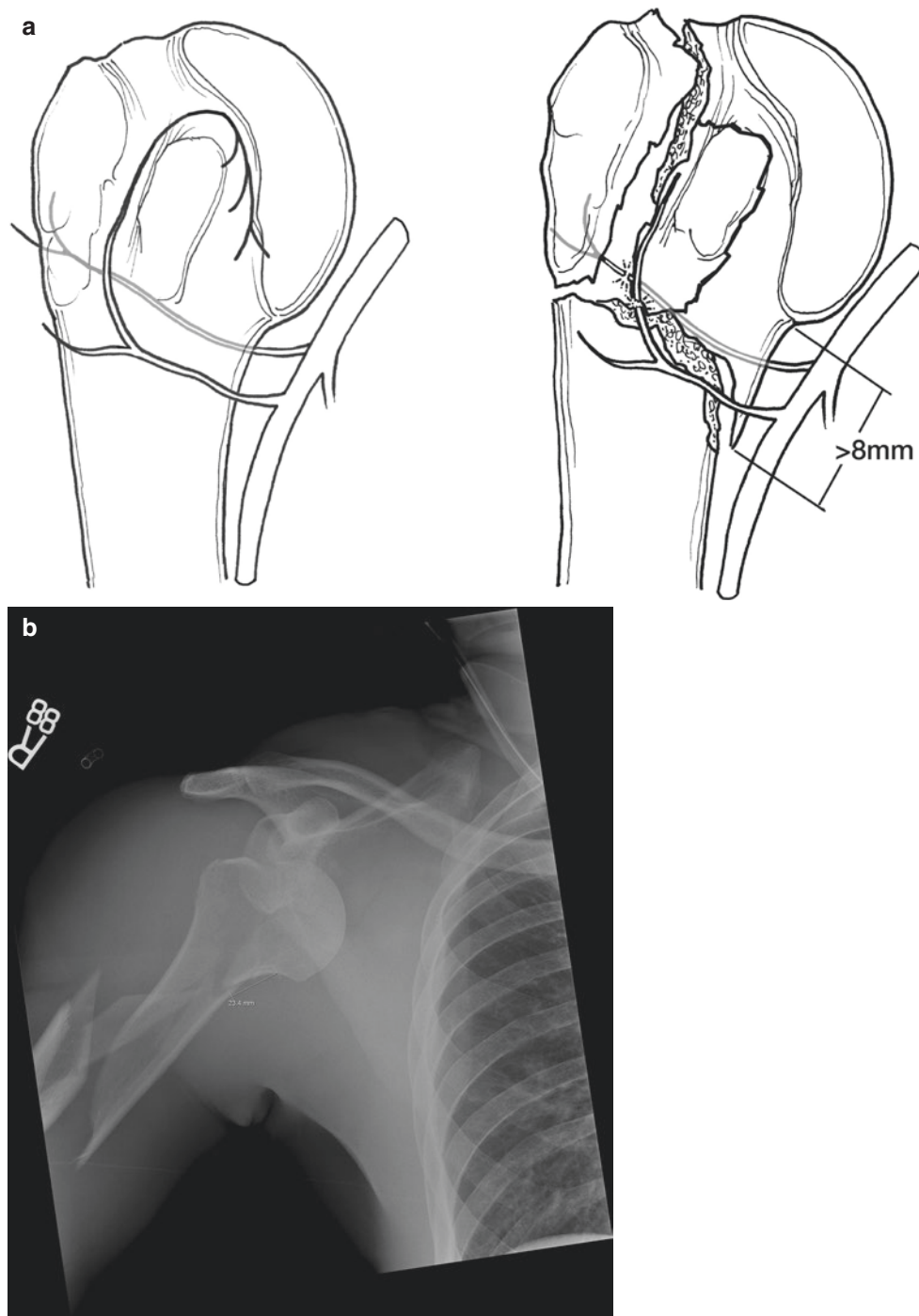
Protocol requires acknowledgement of Dr. Neer's contributions to our understanding of proximal humeral fractures [21, 22]. Neer, who also cites the work of Codman regarding one- to four-segment injuries of the proximal humerus, promoted the classic "part" classification system (Fig. 9.1).

**Fig. 9.1** Neer classification of displaced proximal humeral fractures [21]

		2 part	3 part	4 part	
Minimal displacement					
II Anatomical neck					
III Surgical neck					
IV Greater tuberosity					
V Lesser tuberosity					Articular surface
VI Fracture dislocation	Anterior				
	Posterior				
Head splitting					

Many fractures, including the more comminuted ones, may be treated nonoperatively, if not displaced. Issues arise with fragment displacement and the associated soft tissue injuries, rotator cuff tears, and blood supply disruption, which have an impact on healing and may lead to subsequent avascular necrosis. Neer commented that 1-cm displacement or fracture fragment angulation greater than 45° constitutes significant displacement. Greater tuberosity displacement more than 1 cm from the lesser tuberosity is considered pathognomonic of a longitudinal tear in the rotator cuff [21, 22]. The source

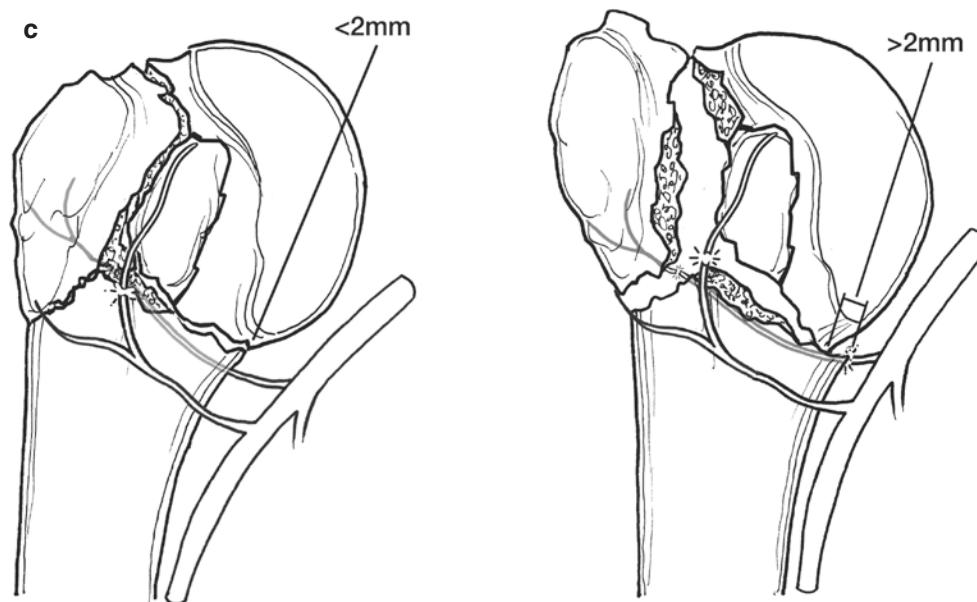
or genesis of Neer's criteria, other than the statement in his article, is difficult to identify. Recent studies on greater tuberosity fractures demonstrate that only 3–5 mm of displacement is tolerated, with 5 mm associated with a 50% incidence of rotator cuff tear [23–29]. In reference to the impact of such fractures on the head's normal blood supply, Hertel *et al.* [30] demonstrated the significance of the anatomic neck fracture with less than 8 mm of medial neck continuity and greater than 2 mm step-off at the head/neck juncture, which has a very high incidence of avascular necrosis (Fig. 9.2).



**Fig. 9.2** (a) Humeral head with intact anterior and posterior humeral circumflex arterial systems, and fracture with at least 8 mm medial neck component and preserved arterial component posteriorly. (b) Radiograph of right proximal humeral fracture with good medial neck length. (c) Humeral head and neck fracture with less than and

greater than 2 mm of medial neck displacement and disrupted posterior humeral circumflex system. The anterior humeral circumflex artery is the primary blood supply, but when the proximal humerus is fractured, the major blood supply comes from the posterior humeral circumflex artery





**Fig. 9.2** (continued)

It is difficult to be dogmatic about the diverse treatment options for the spectrum of fractures. The heavy emphasis on fixation in this chapter must be tempered with the understanding that many, if not most, proximal humeral fractures are treated nonoperatively. The treating surgeon's enthusiasm for surgical intervention usually mellows with the passage of time, with the realization that radiographically dissatisfying alignment can still result in very functional patient outcomes, particularly in the more "mature" patient.

Many studies have reviewed operative and nonoperative treatment. Short of fracture dislocations, patients do very well with significant displacement. Two-part fractures (surgical neck type) with shaft displacement up to 60% and varus alignment still heal with functional outcomes [31, 32]. I generally intervene in a varus situation if the head tilts such that the greater tuberosity is above the dome of the humeral head. But even with this criterion, patients may still elect nonoperative treatment and function very well—not normally, but well (Fig. 9.3).

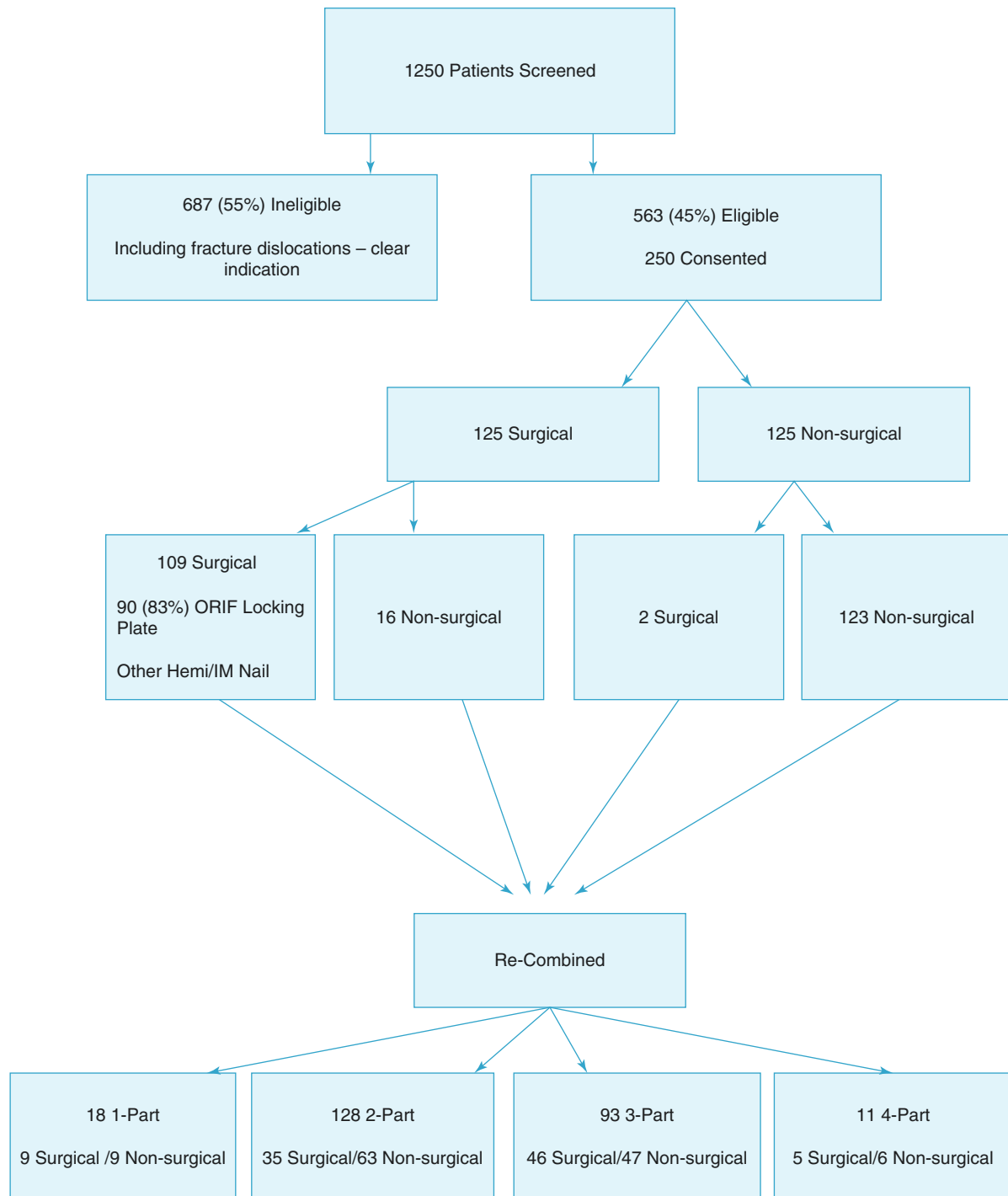


**Fig. 9.3** (a) Radiograph of patient previously treated for a distal humeral fracture with new fracture, who elected nonoperative treatment despite the head being in varus and counseling about potential surgery.

(b, c) Radiographs at the time of discharge, with the patient having returned to her previous occupation without complaints

The prospective, multicenter Proximal Fracture of the Humerus Evaluation by Randomization (PROFHER) study [33] compared operative and nonoperative treatment. The

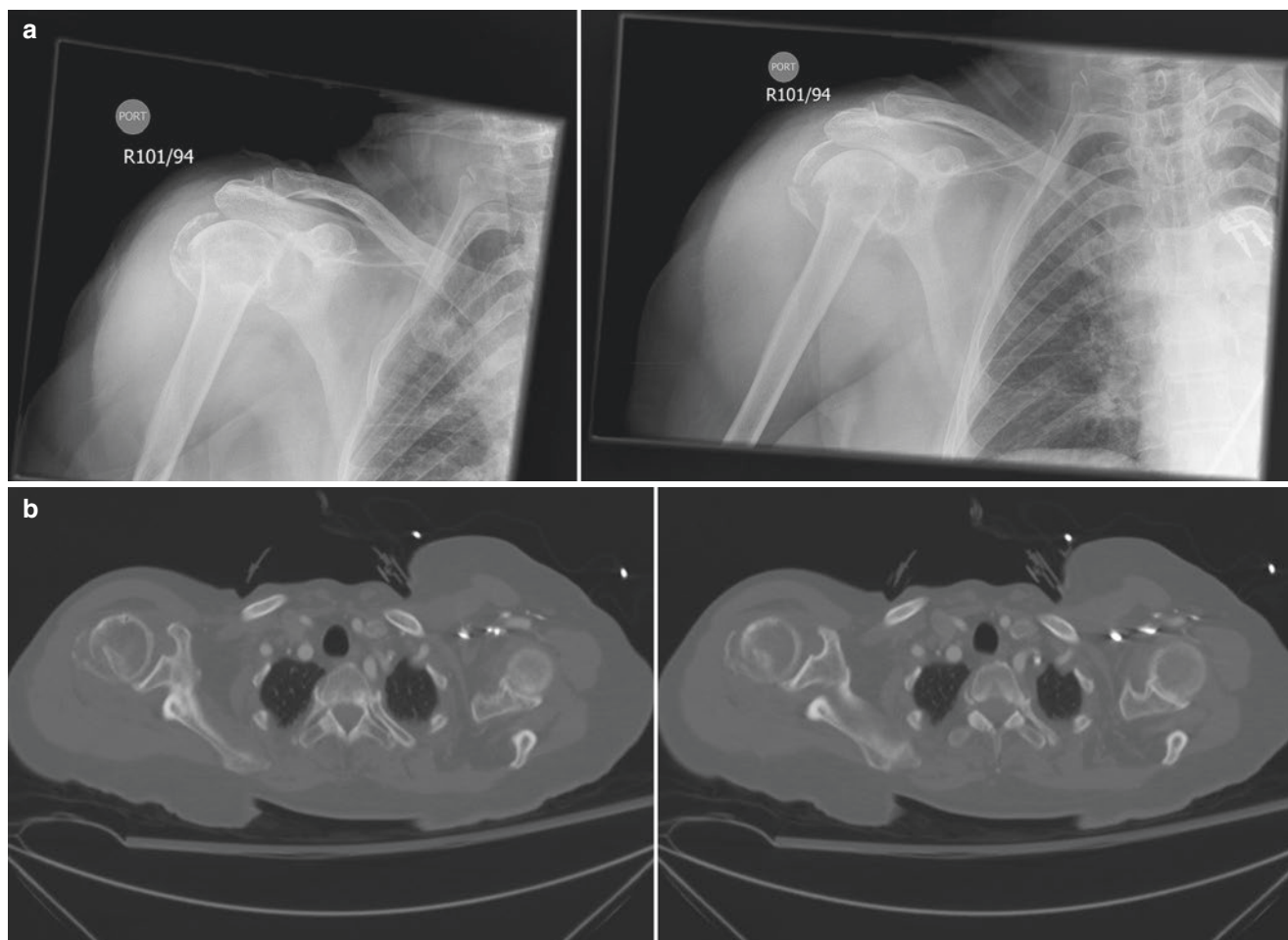
flow chart in Fig. 9.4 summarizes the conclusions, realizing that fracture dislocations were excluded, along with “obvious” indications for surgery.



**Fig. 9.4** Proximal Fracture of the Humerus Evaluation by Randomization (PROFHER) flow chart [33]

Looking at the number of patient with fractures in the groups that tend to be controversial (three- and four-part fractures), I feel the numbers are still small for the conclusion that equal outcomes are achieved operatively and

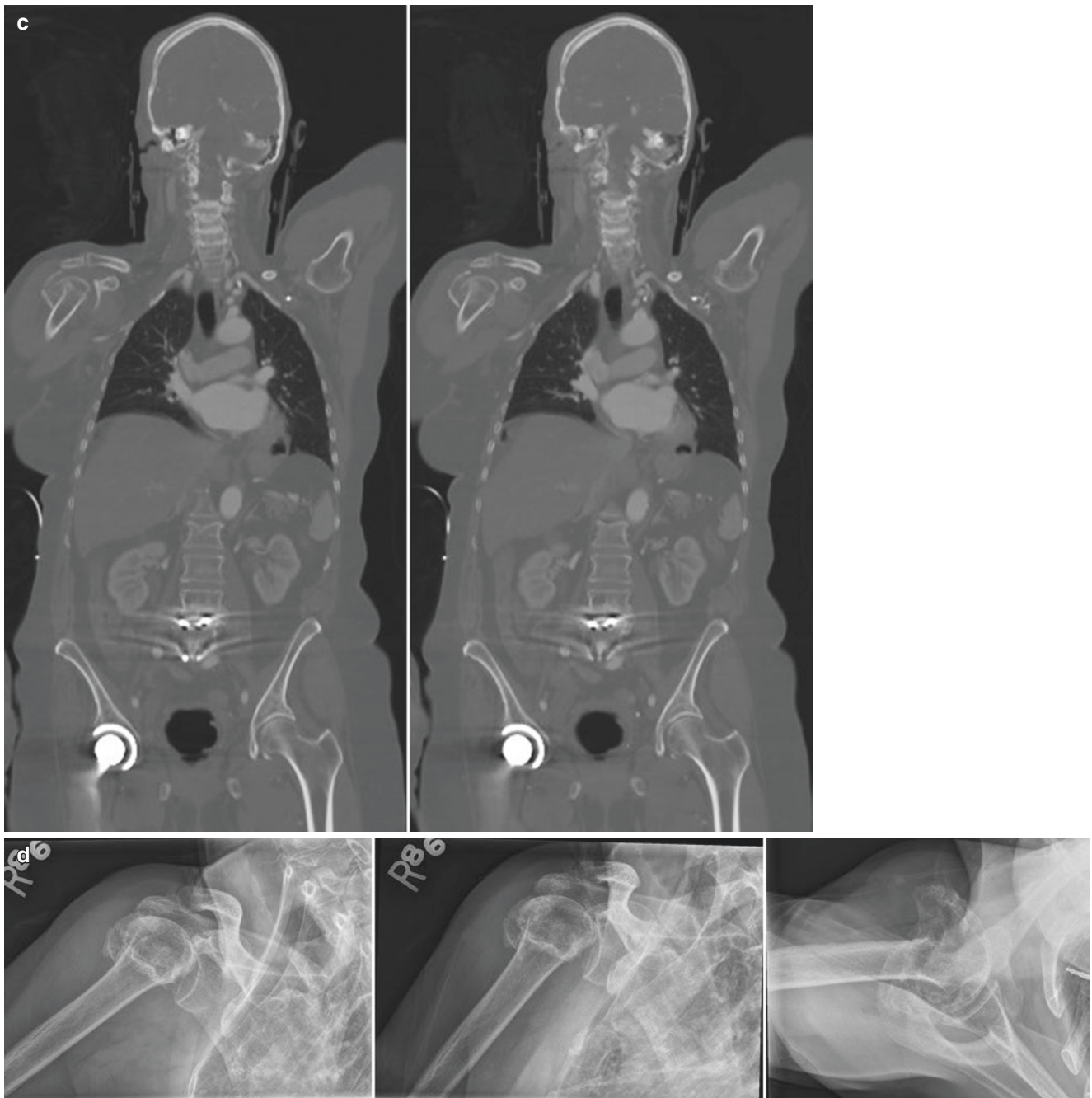
nonoperatively. Noting my reservation about the PROFHER study, I have treated and do treat fractures with significant displacement nonoperatively, pending individual and medical concerns, as illustrated in Fig. 9.5.



**Fig. 9.5** (a) Radiographs of valgus-impacted right proximal humeral fracture in an elderly patient treated with a sling and early range of motion. (b) Axial CT scan of right proximal humeral fracture, revealing humeral head contact with glenoid. (c) Coronal CT scan revealing the

degree of valgus impaction with some joint contact. (d) Follow-up radiographs at time of discharge. Patient had returned to driving, with no complaints at 8 weeks following her injury





**Fig. 9.5** (continued)

## 9.2 Surgical Approach

If I decide to operate, my general credo has been to get the head over the shaft, get out of varus, and have the greater tuberosity below the dome of the humeral head. Please note that this does not necessarily mean anatomic, as I would default to soft tissue preservation of the fracture to improve union rather than achieving a pretty

radiograph, knowing that the functional outcomes may not correlate.

Once I've decided to proceed with surgical intervention, the setup for the proximal humerus approach is the same for a variety of injuries, whether the injury be a glenohumeral dislocation with greater tuberosity fracture, fracture dislocation, or surgical neck fracture (Figs. 9.6, 9.7, 9.8, 9.9, 9.10, 9.11, 9.12, 9.13, 9.14, 9.15, 9.16, 9.17, 9.18, 9.19, 9.20, 9.21, and 9.22).



**Fig. 9.6** Patient positioning and set-up on radiolucent table with metal clamp that could block C-arm pictures



**Fig. 9.7** Arm board with thick pad and clamp that attaches directly to radiolucent table



**Fig. 9.8** Arm board attached; note support of arm with thick pad



**Fig. 9.9** Arm board positioned at axilla level to prevent obstruction of C-arm shots. Leave the arm board out at a right angle during the prepping and draping. Note the two folded sheets behind the shoulder to rotate the shoulder for radiographic purposes





**Fig. 9.10** Predrapping with single-edge adherent barrier



**Fig. 9.11** No barrier posteriorly prevents puddling of preparation solution



**Fig. 9.12** Absorbent predraping around perimeter



**Fig. 9.13** Absorbent predraping around perimeter



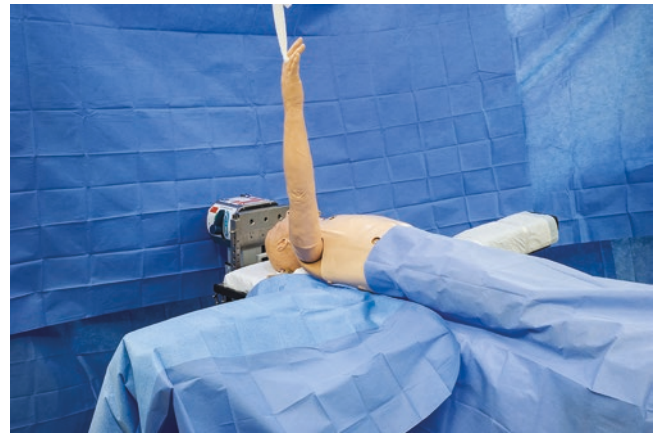
**Fig. 9.14** Absorbent predraping around perimeter



**Fig. 9.15** Body drape



**Fig. 9.16** Three-fourths reinforced drape over arm board. Drape with arm board out, not tucked in; swinging the arm board out is more difficult when draped at the side



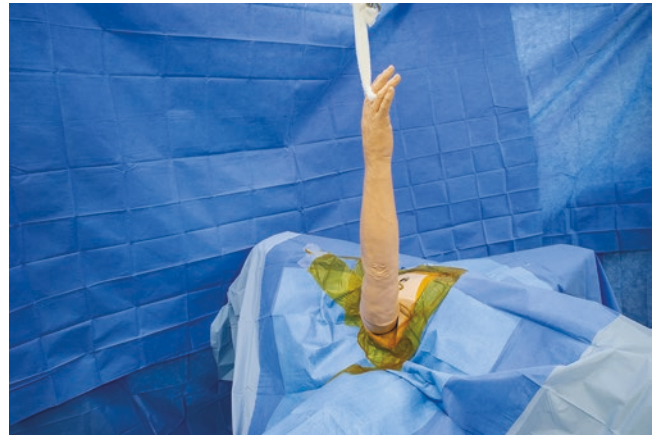
**Fig. 9.17** Four towels around the field. Drape from out to in so as not to contaminate your gown by trying to put the towels down first



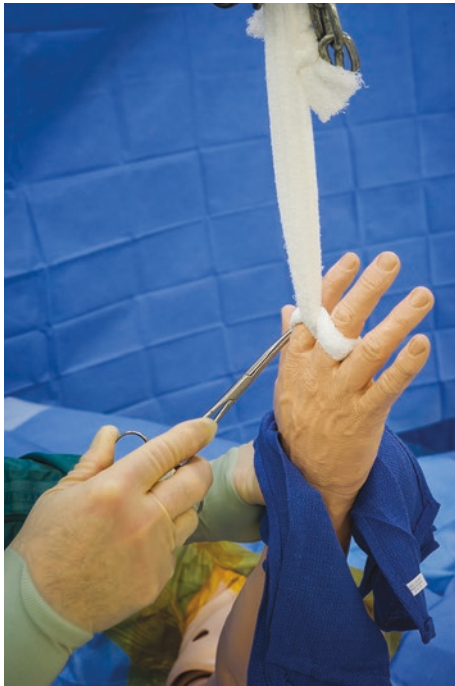
**Fig. 9.18** Split sheet with the tails down coming from the opposite side



**Fig. 9.19** Split sheet with the tails up



**Fig. 9.20** Ioban® sealing drapes



**Fig. 9.21** Hand taken down from suspension using Kelly clamp (not Kocher) so as not to cut the patient

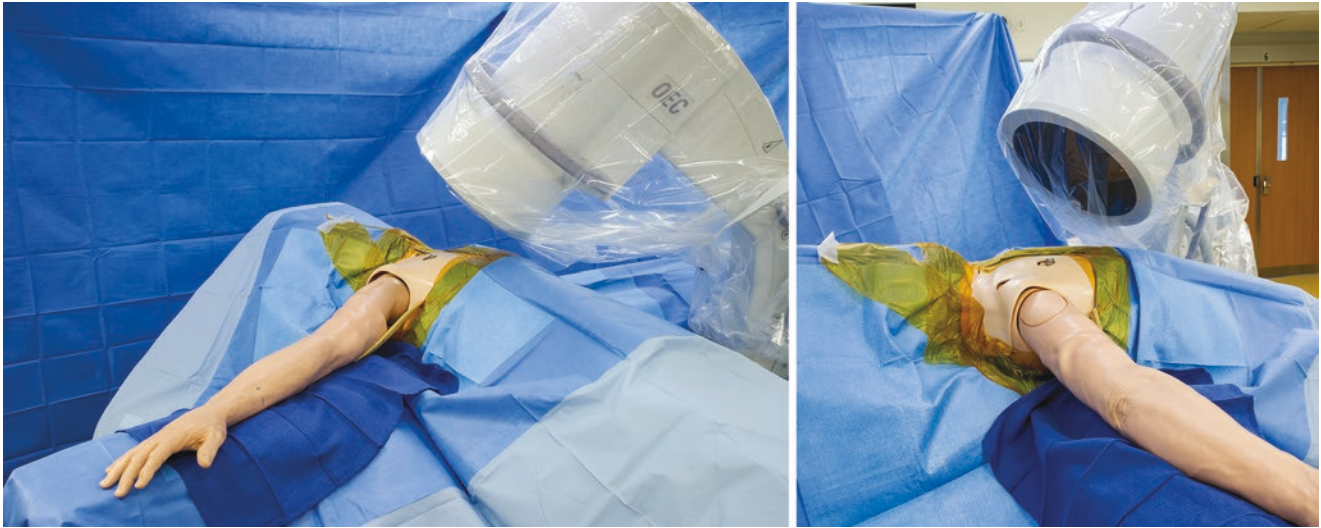


**Fig. 9.22** Fingers painted

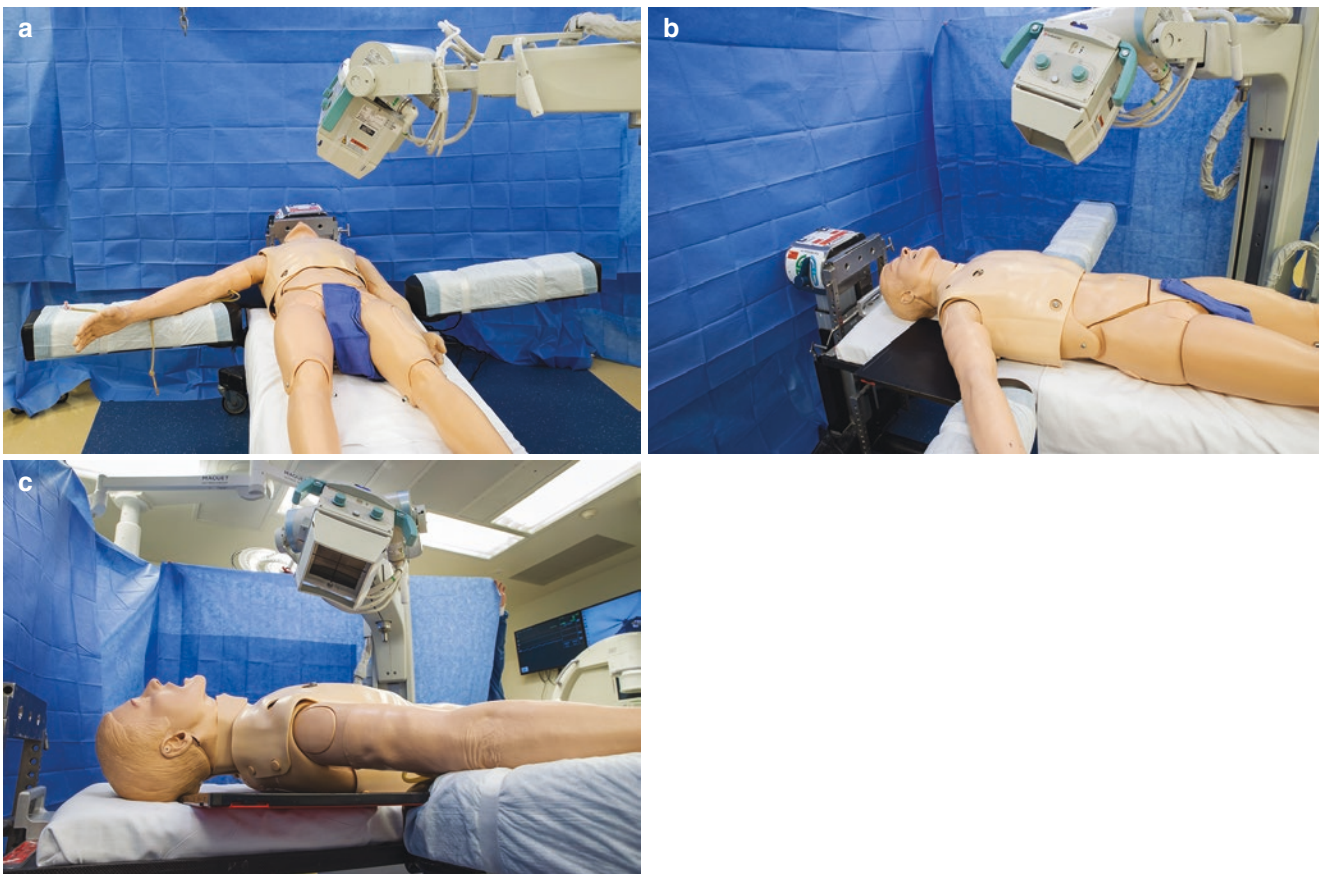
I use an OSI table with a two-sheet bump behind the injured shoulder. The patient is moved to the operative side with an arm board that is radiolucent.



The C-arm comes from the opposite side and will be used in the Grashey and Y-scapular fashion (Figs. 9.23 and 9.24).



**Fig. 9.23** C-arm positioned for Grashey view



**Fig. 9.24** (a–c) X-ray machine positioned for postoperative Grashey radiographs



If an axillary view is required to address fracture dislocations, it would be performed using intraoperative flat plates (Fig. 9.25).



**Fig. 9.25** Positioning for axillary radiographs

The approach to the proximal humerus is the deltopectoral approach. A generic lateral plating will be demonstrated with the various nuances of specific fractures presented in subsequent cases. I have not utilized a lateral approach except in intramedullary nailing, where I come off the acromion in a fashion that allows more longitudinal orientation of the intramedullary device. I can't get my head around the "whys" of a direct lateral or deltoid split approach when a nice deltopectoral approach, with its extensile virtues, is sitting right there if needed (Fig. 9.26).



**Fig. 9.26** Incision outlined for deltopectoral approach. The circle represents the coracoid process

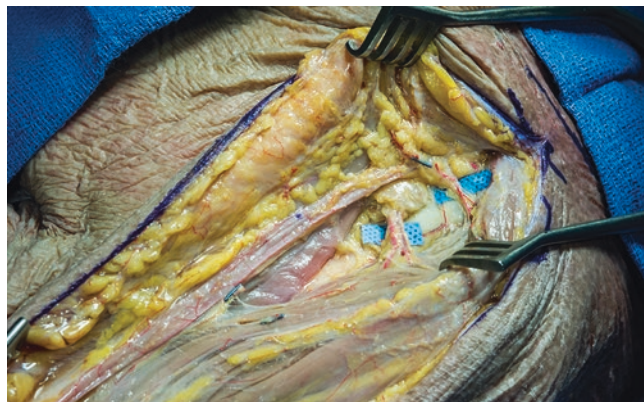
The incision begins at the level of the clavicle and courses along the deltopectoral interval to the deltoid insertion. Palpation of the coracoid, if possible, facilitates defining the interval. If further extension is required distally, I sweep the incision laterally then course back somewhat medially, ending in the biceps brachialis and brachioradialis interval distally. I do not use tourniquets for proximal fracture, but a slightly more distal one will be considered predicated upon the level of the fracture.

Once the incision is performed, dissection through the subcutaneous tissue is frequently performed with a Bovie. I identify the cephalic vein and I prefer to mobilize the vein medially, acknowledging that Radkowski *et al.* found the number of perforators into the deltoid to be about twice those in the pectoralis major [34]. I find that maintaining the cephalic vein medially, particularly in proximal fracture fixation, allows more proximal access without tensioning the vein. Difficulty in finding the interval is facilitated by dissecting proximally, looking for the fat pad between the deltoid and the pectoralis major, and then continuing distally. I dissect the vein away from the deltoid and use LigaClips® for venous control. There is a vascular complex from the thoracoacromial artery proximally, followed generally by two or more perforators coursing into the deltoid; these should be controlled with LigaClips® (Figs. 9.27, 9.28, 9.29, 9.30, 9.31, and 9.32).

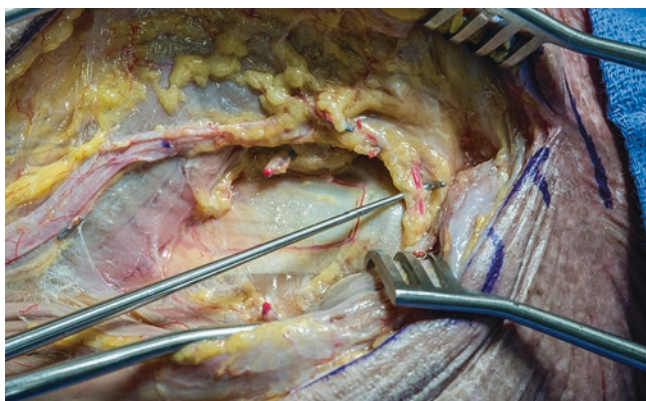




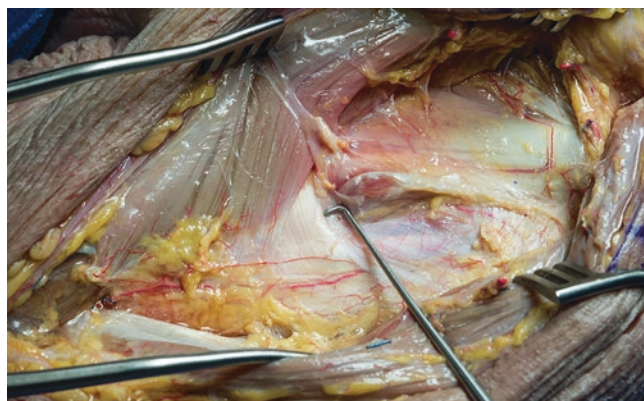
**Fig. 9.27** Cephalic vein medial with tributaries to the deltoid (one highlighted with blue background)



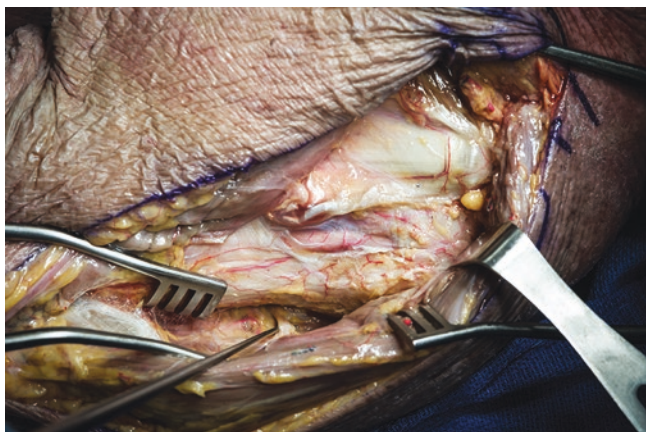
**Fig. 9.28** Proximal tributaries. Note LigaClips® on tributaries distally



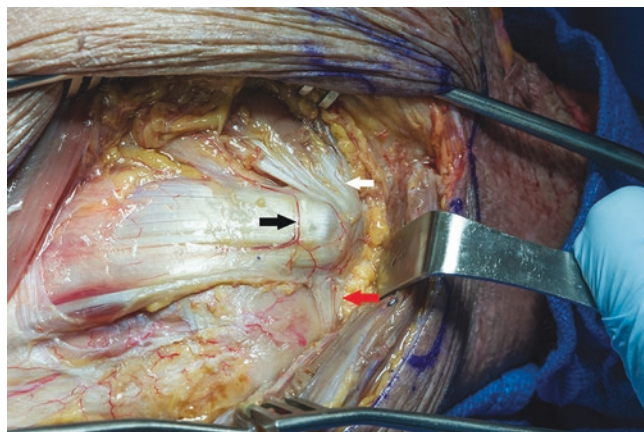
**Fig. 9.29** Thoracoacromial branches over coracoid process



**Fig. 9.30** Superior edge of pectoralis major tendinous insertion, used as a landmark for prosthesis insertion



**Fig. 9.31** Axillary nerve at end of nerve hook

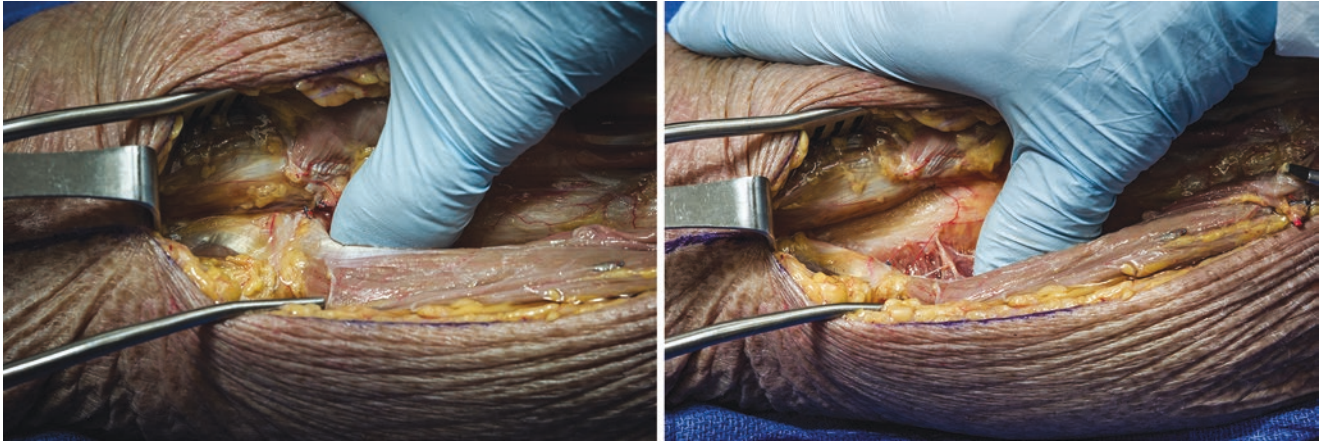


**Fig. 9.32** Conjoint tendon (*black arrow*), pectoralis minor (*white arrow*), and coracoacromial ligament (*red arrow*)



The deltoid is retracted laterally with a cobra retractor posteriorly over the humeral head, exposing the fracture and the proximal shaft. I elevate the leading edge of the deltoid

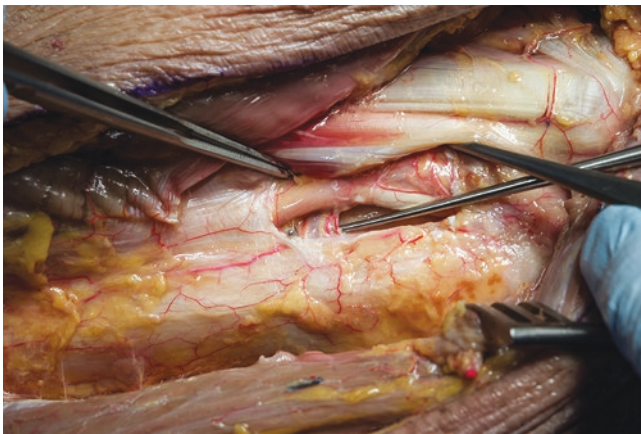
off, generally bluntly, with what I call a “thumb roll” technique (Fig. 9.33).



**Fig. 9.33** “Thumb roll” elevating the leading edge of the deltoid insertion, which comes off as a nice sleeve

A subacromial bursectomy is then carried out. I am very adamant that I do not perform a coracoacromial ligament resection, and I am very careful to preserve the biceps tendon. I have never done an elective biceps tenodesis, and I have never needed to go back and do a biceps tenodesis

because of the presumed pain generator. I use the biceps tendon for rotational determination, such that a linear biceps tendon will help you further evaluate the rotational status (Figs. 9.34, 9.35, 9.36, and 9.37).

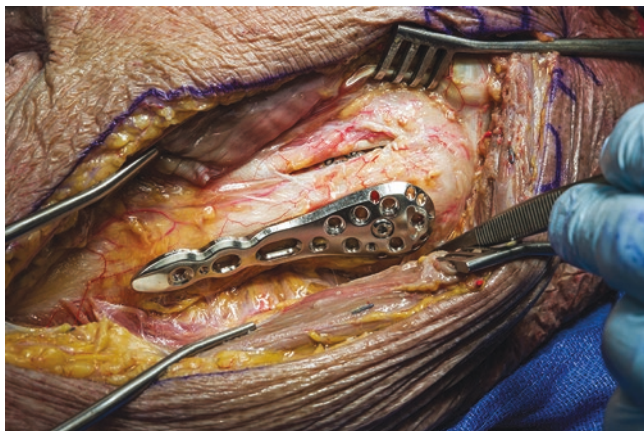


**Fig. 9.34** Anterior humeral circumflex vessels



**Fig. 9.35** Plate positioning in the bicipital groove for provisional fixation





**Fig. 9.36** Proximal humeral plate positioned laterally over the greater tuberosity



**Fig. 9.37** Plates exposed, showing relationship to the bicipital groove and greater tuberosity

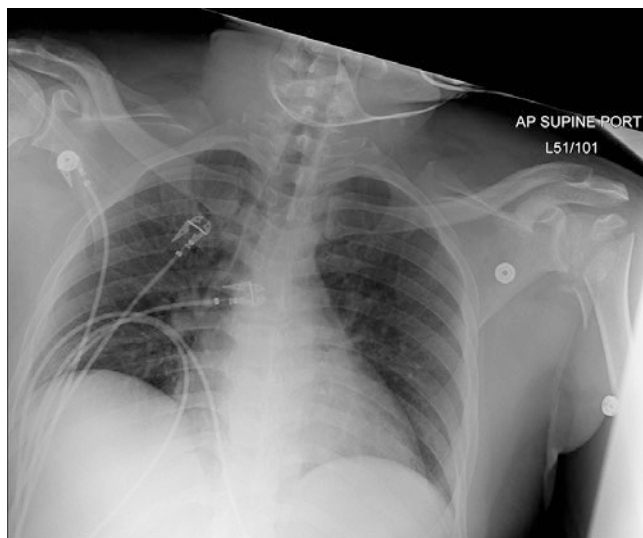
If access medially is required to retrieve a dislocated humeral head, I perform a coracoid osteotomy: I identify the pectoralis minor and the conjoint tendon, and then I do a V-chevron osteotomy, thus preserving the coracoacromial ligament and the pectoralis minor insertion. The osteotomy will be subsequently stabilized with a longitudinal 0.045 K-wire, followed by either a 20- or 22-gauge interosseous wire loop. I do not predrill because the fragment is so small that I've had problems finding the hole again without splitting the fragment (Figs. 9.38, 9.39, 9.40, 9.41, 9.42, 9.43, 9.44, 9.45, and 9.46).



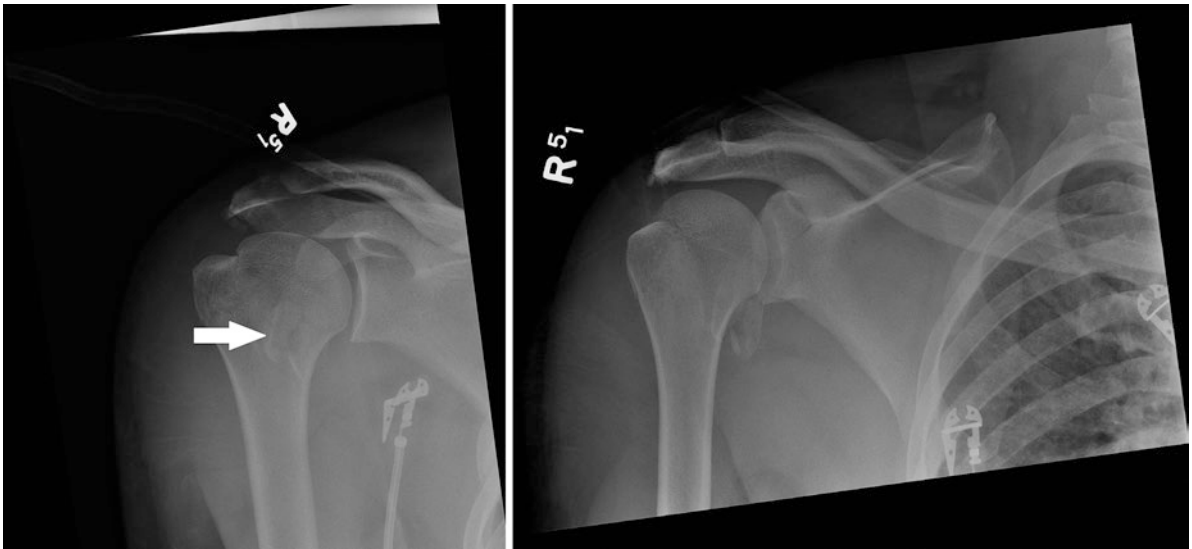
**Fig. 9.38** Demonstration of coracoid osteotomy, with reflection of the conjoint tendon



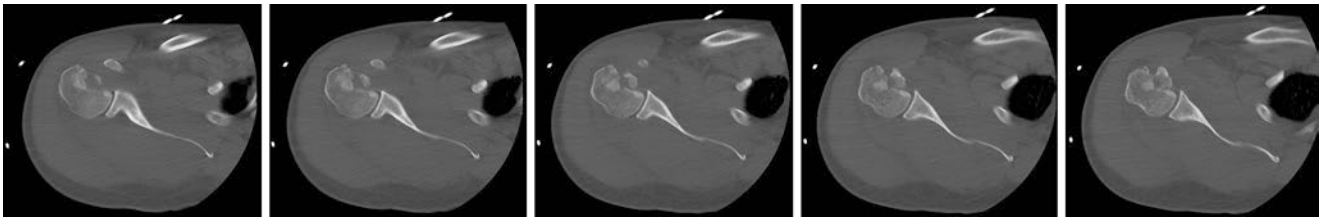
**Fig. 9.39** Musculocutaneous nerve piercing the coracobrachialis



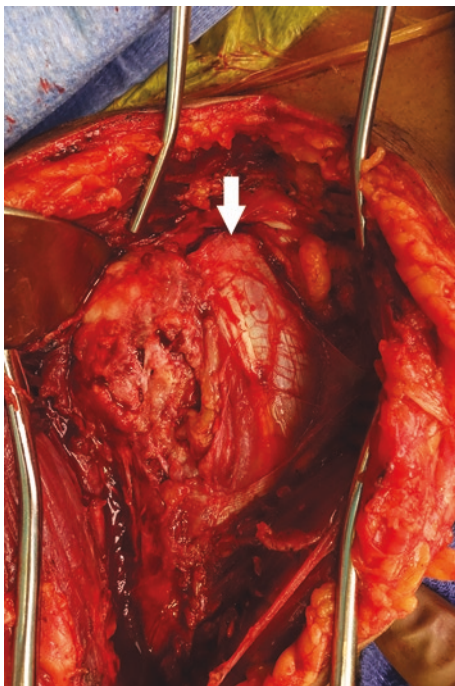
**Fig. 9.40** Chest radiograph on presentation from outside hospital for bilateral shoulder dislocations following seizures. Right side was reduced; left side is still dislocated



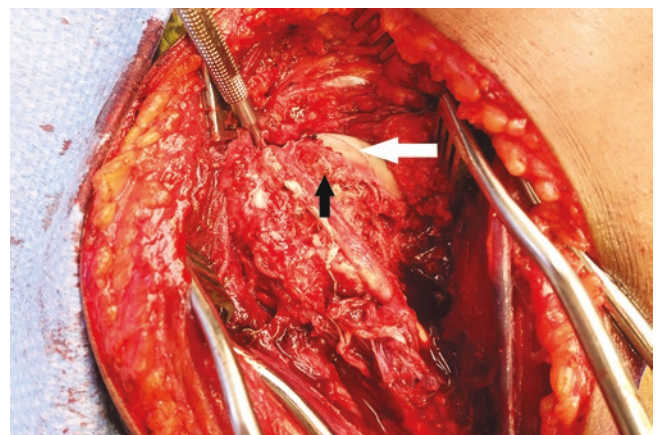
**Fig. 9.41** Radiographs of right shoulder demonstrating lesser tuberosity fracture (*arrow*)



**Fig. 9.42** CT scan of right shoulder demonstrating large anterior head defect

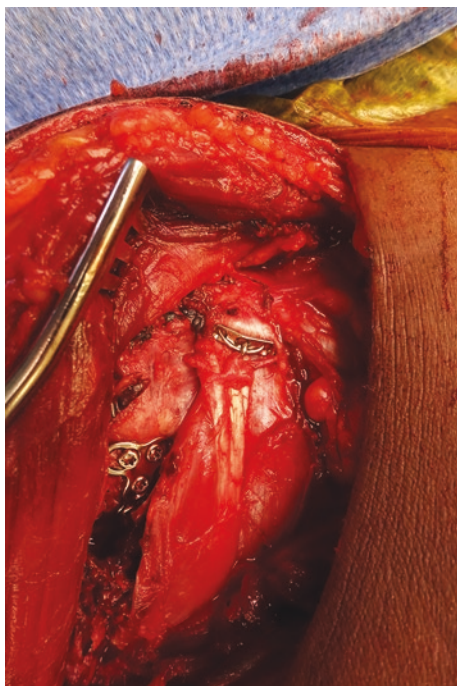


**Fig. 9.43** Right proximal humeral fracture exposed through deltopectoral approach with conjoint tendon (*arrow*) exposed prior to osteotomy

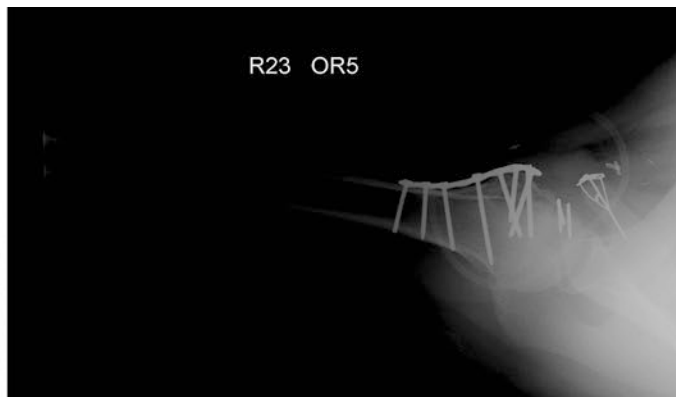


**Fig. 9.44** Impacted fragment (*white arrow*) elevated and rafted with Kirschner wires (K-wires) (*black arrow*)





**Fig. 9.45** Conjoint tendon and osteotomy reduction and fixation



**Fig. 9.46** Radiographs following open reduction and internal fixation



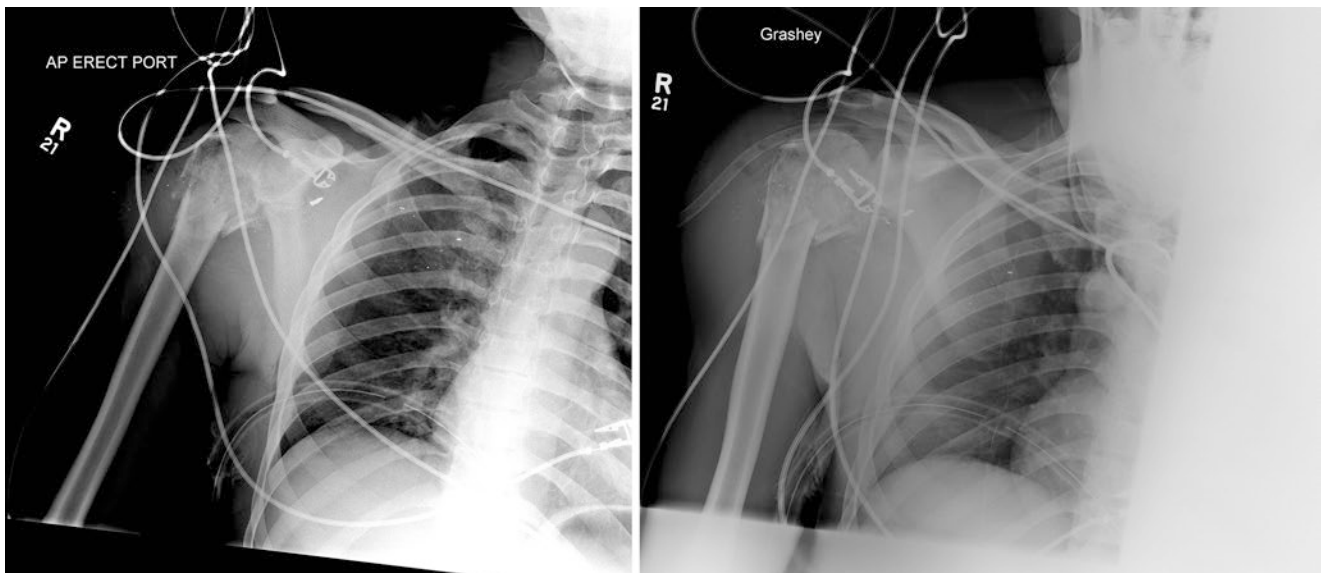
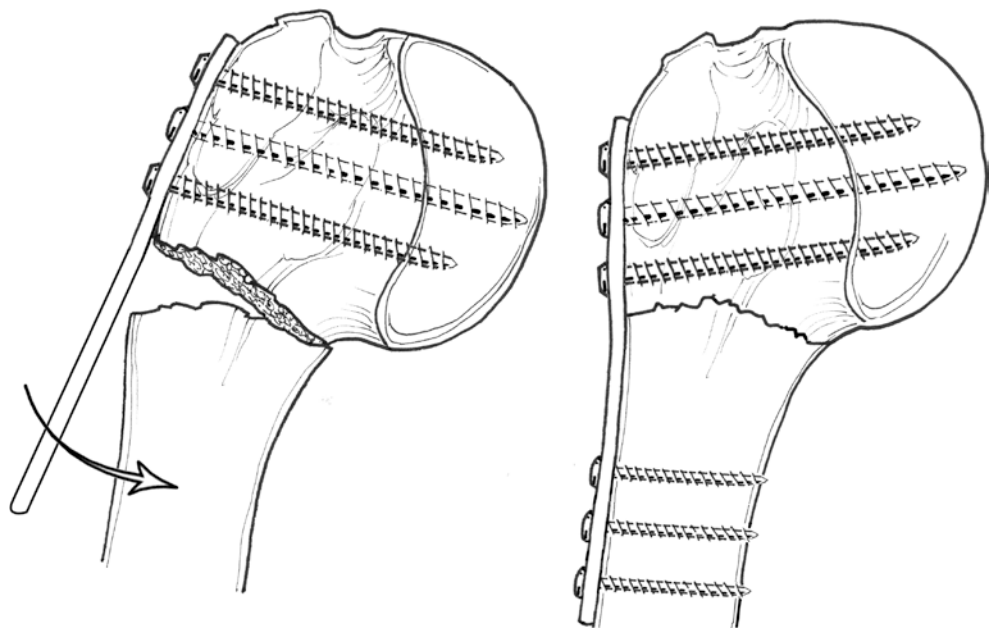
### 9.2.1 Case Examples: Two-Part Fractures

We will begin the case examples with simpler patterns or the two-part fracture, including surgical neck and isolated greater and lesser tuberosity fractures. The two major conditions to be critiqued with surgical neck fractures are the neck shaft displacement and varus angulation. (I do not know if I have seen a two-part valgus fracture.) The decision to operate on a varus two-part fracture, as noted, is generally driven by the location of the greater tuberosity above the dome of the humeral head. The fixation selection is almost emotion-based, as nails and plates have similar outcomes. Even a nondisplaced

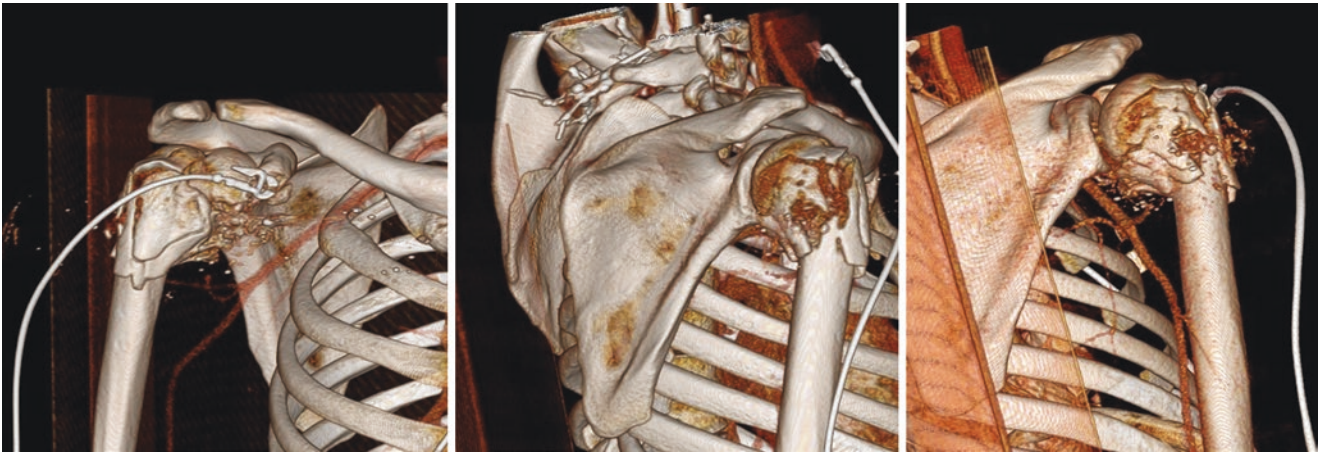
greater tuberosity fracture will not preclude intramedullary fixation.

The humeral head in a varus position can be reduced starting with placement of the plate on the head. The plate is first placed, then secured with a centering cancellous screw, typically followed by two locking screws in the humeral head; this is opposite the procedure for the valgus head, where the screws are placed in the shaft first. After the plate is secured to the humeral head, the stem of the plate is delivered to the shaft, effecting reduction. Reduction and provisional plate or K-wire fixation can be used, but I have found that plate-assisted reduction works well (Figs. 9.47, 9.48, 9.49, 9.50, 9.51, 9.52, 9.53, 9.54, 9.55, 9.56, and 9.57).

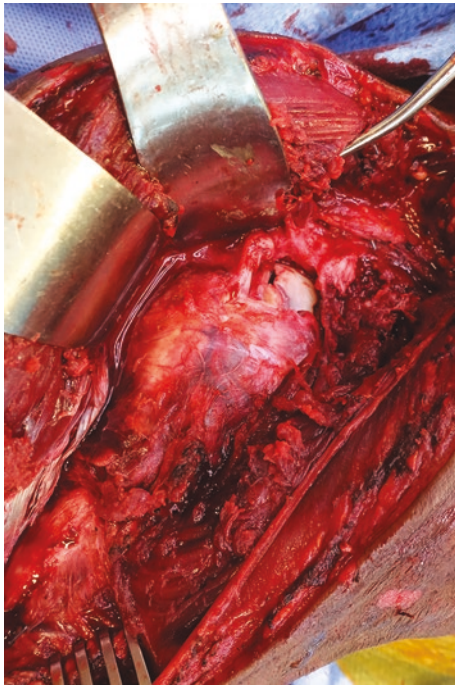
**Fig. 9.47** Technique of plate fixation on head in varus and using the plate for reduction



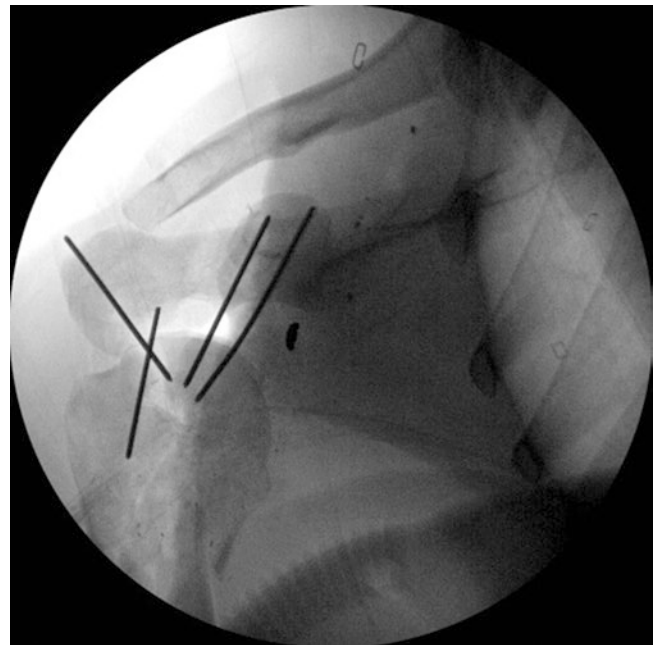
**Fig. 9.48** Injury radiographs demonstrating right proximal humeral fracture in varus; note strategic cords placement



**Fig. 9.49** Three-dimensional (3D) CT scan of proximal humeral fracture secondary to penetrating metallic object

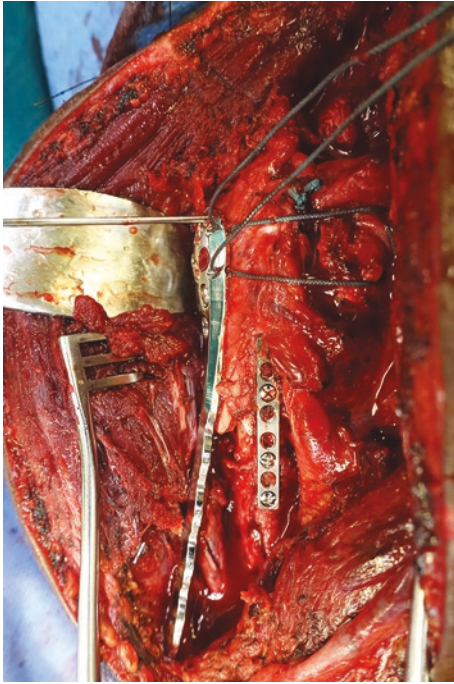


**Fig. 9.50** Right proximal humerus exposure with humeral head exposed



**Fig. 9.51** Intraoperative C-arm radiographs with provisional K-wire fixation





**Fig. 9.52** Plate positioned on the head of the humerus, with the stem of the plate off of the shaft

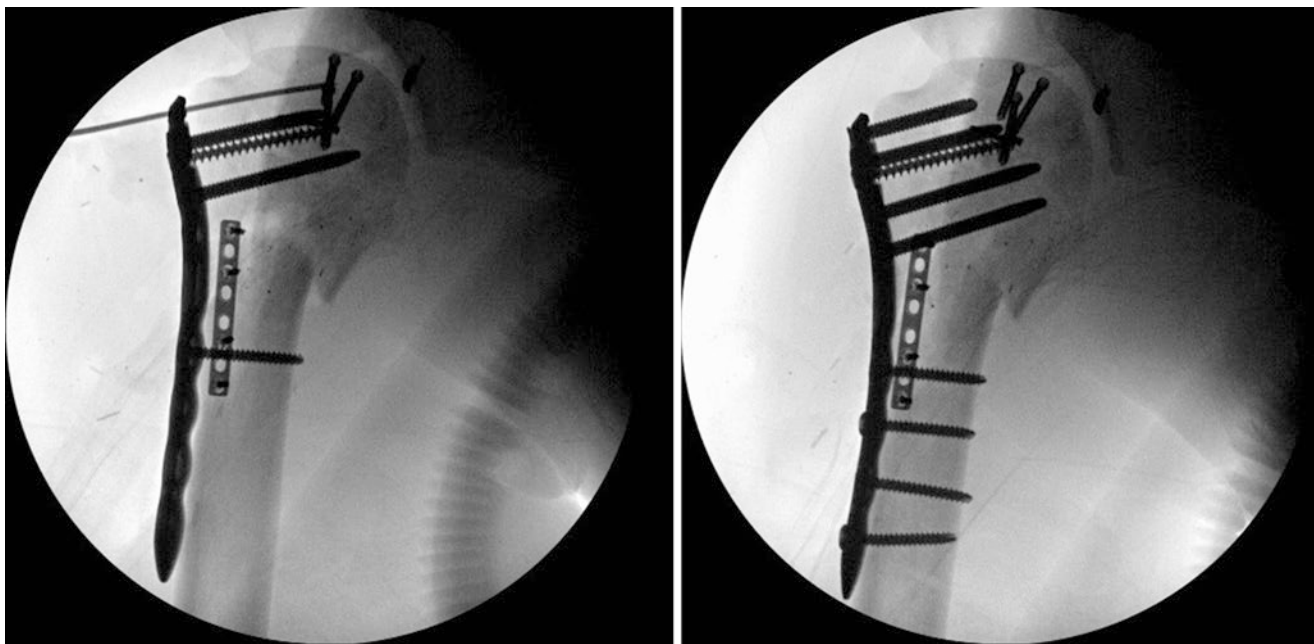
**Fig. 9.54** Plate reduced to shaft, correcting the varus head position



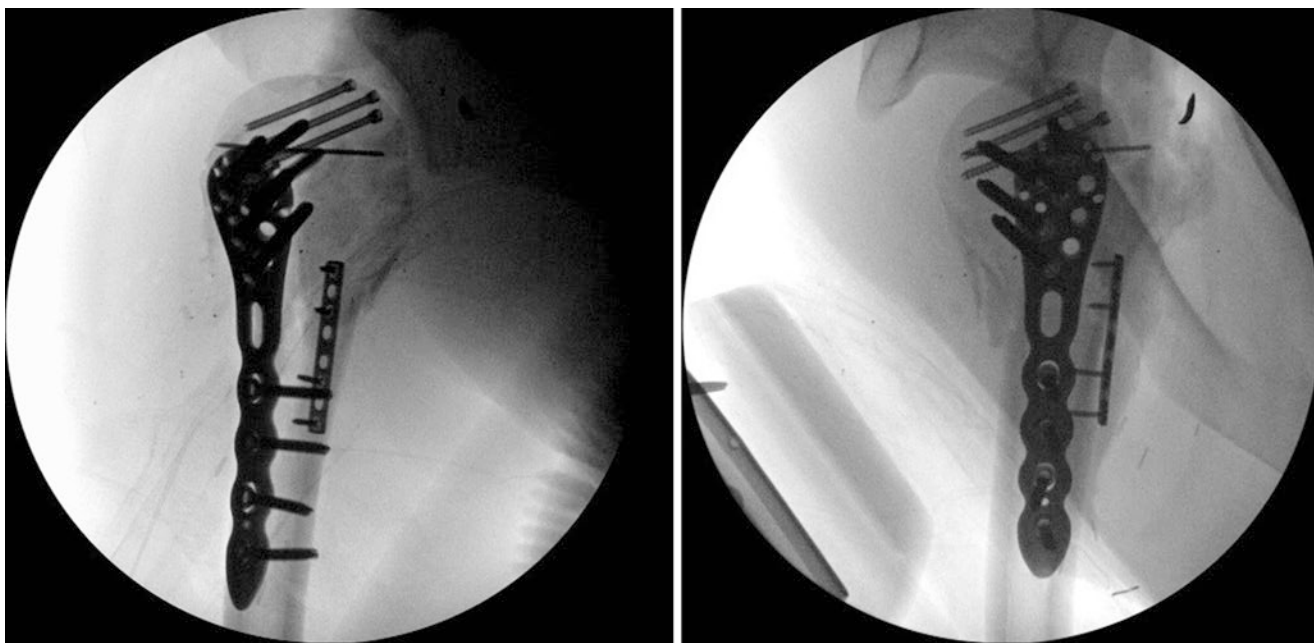
**Fig. 9.53** Intraoperative C-arm radiographs showing plate fixation to humeral head



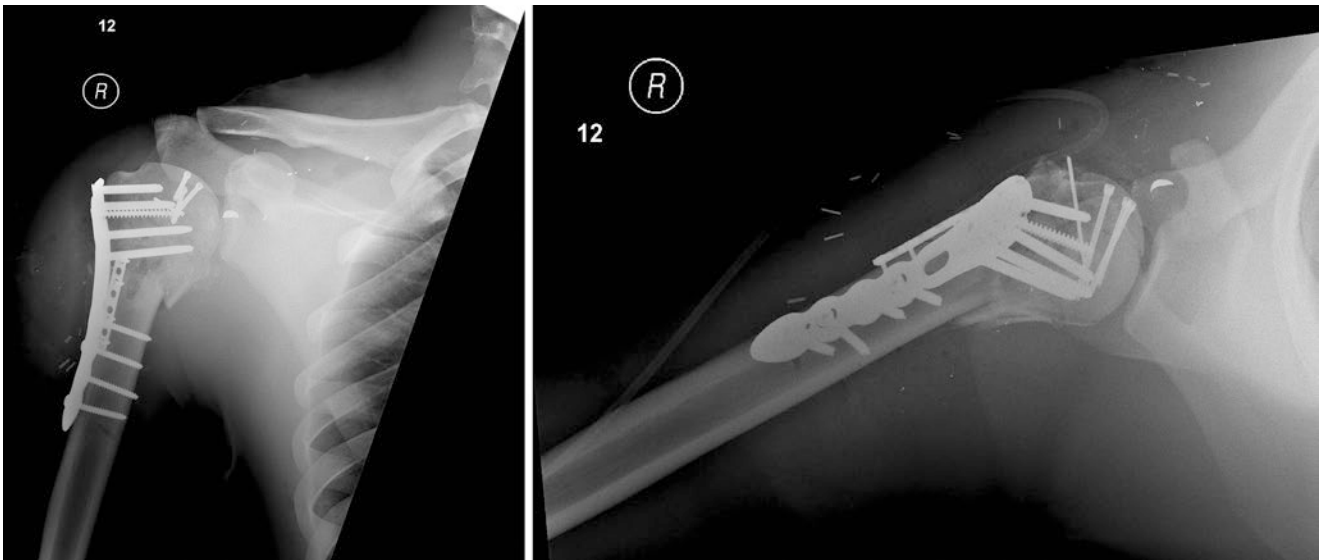




**Fig. 9.55** Intraoperative radiographs showing plate fixation to the humeral shaft with correction of the varus head position



**Fig. 9.56** Final C-arm radiographs



**Fig. 9.57** Postoperative Grashey and axillary radiographs

Greater and lesser tuberosity fractures are commonly associated with dislocations, with the degree of tuberosity displacement that requires fixation still not defined, but somewhere between 3 and 10 mm. Also still unclear is the displacement criterion on a radiograph or CT scan measurement. Greater tuberosity fractures may be addressed with screws, suture anchors, and arthroscopically assisted ORIF, which also allows any rotator cuff pathology to be addressed. I prefer plate fixation, probably in reaction to other techniques that I have seen fail, which were then salvaged with ORIF by using a plate (Fig. 9.58).

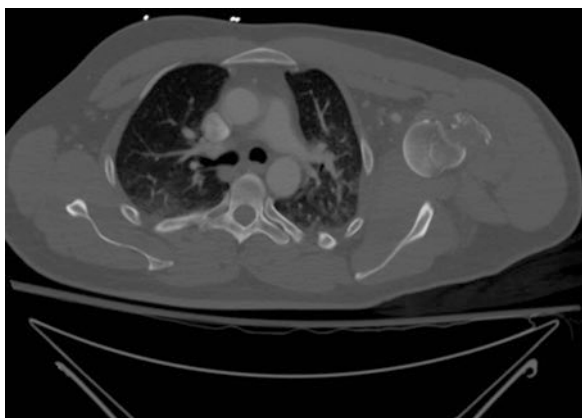
Bone grafting also is frequently required, even if you think things perfectly key back into place (Figs. 9.59, 9.60, 9.61, 9.62, 9.63, 9.64, 9.65, 9.66, 9.67, 9.68, 9.69, 9.70, 9.71, 9.72, 9.73, 9.74, and 9.75).



**Fig. 9.58** Radiographs obtained on referral, showing right proximal humeral fixation with loss of fixation and anterior subluxation



**Fig. 9.59** Radiograph of left proximal humeral fracture dislocation with greater tuberosity fracture

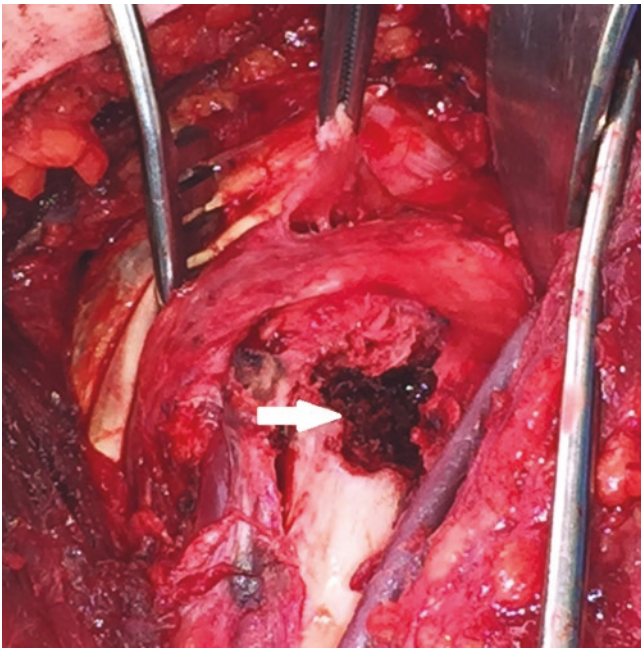


**Fig. 9.60** CT scan demonstrating displaced greater tuberosity and defect in dislocated head

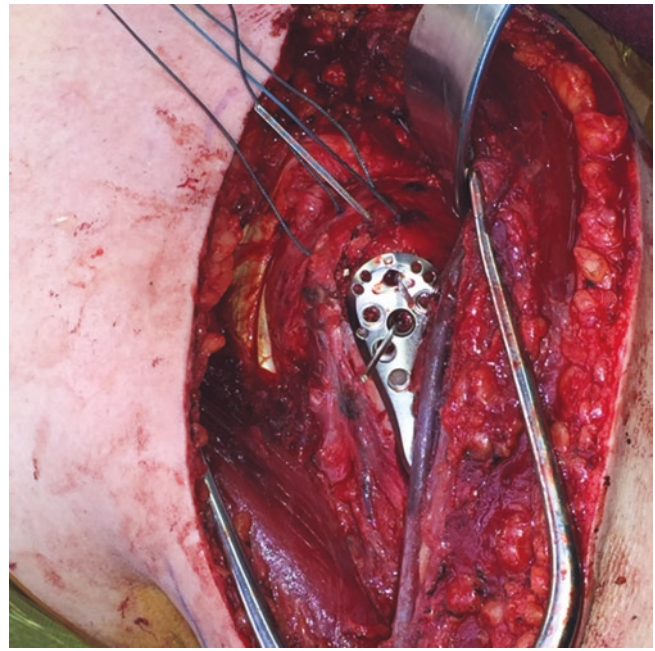


**Fig. 9.61** Radiographs following reduction with displaced greater tuberosity



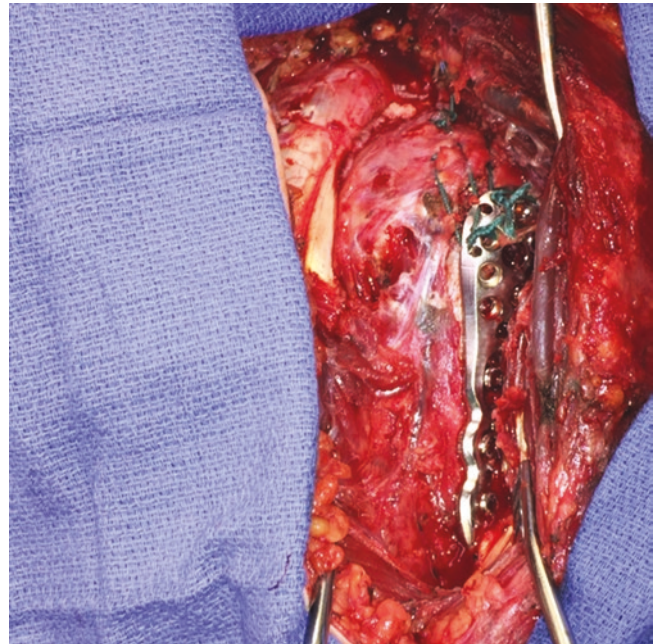


**Fig. 9.62** Left proximal humeral fracture exposed with large defect (*arrow*) to be bone grafting. Note the cephalic vein lateral, not medial, secondary to a zone of injury medial to the vein



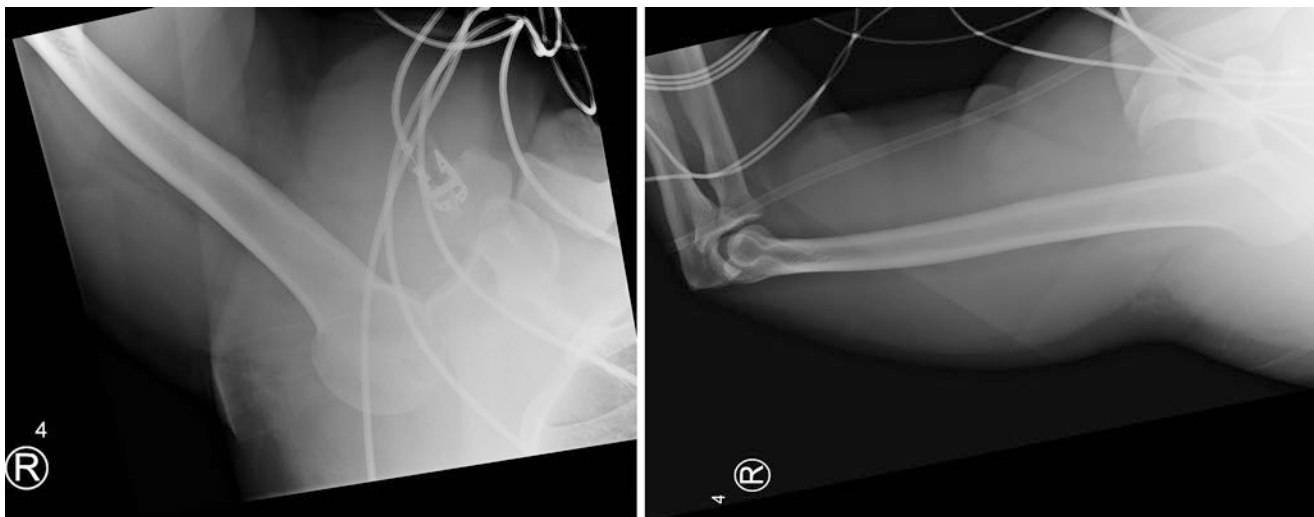
**Fig. 9.63** Bone graft inserted, greater tuberosity reduced, plate provisionally positioned to be removed to allow cuff sutures to be placed through the plate

**Fig. 9.64** Final fixation with cuff sutures tied

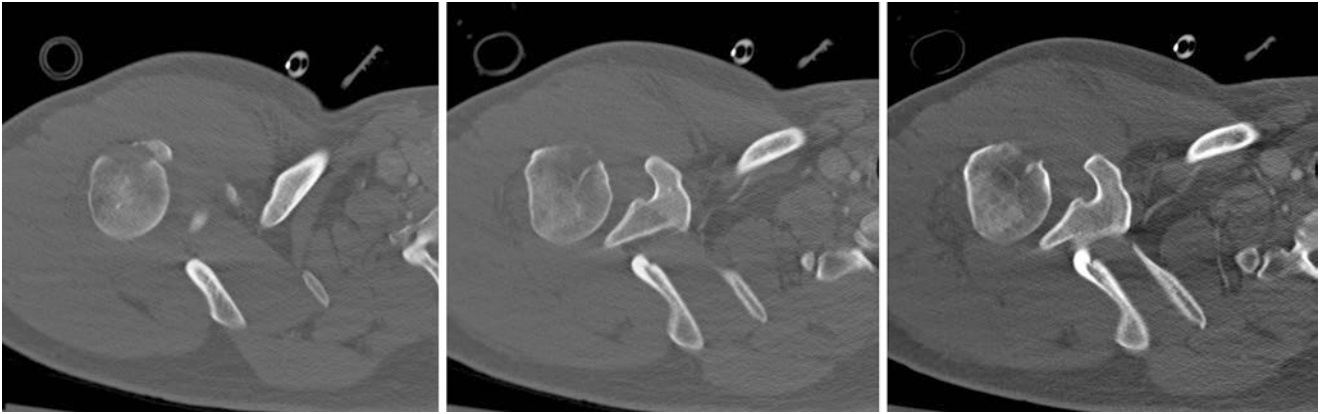




**Fig. 9.65** Follow-up Grashey and axillary radiographs, showing some resorption in cephalic sulcus despite bone grafting



**Fig. 9.66** Right shoulder fracture dislocation, with luxatio erecta



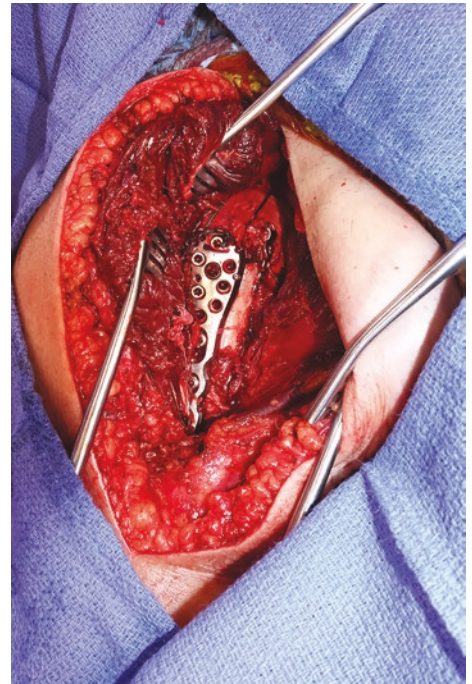
**Fig. 9.67** CT scan following reduction, with bone defect in head at the site of the greater tuberosity fracture



**Fig. 9.68** Coronal CT scan demonstrating greater tuberosity displacement and nondisplaced neck fracture



**Fig. 9.69** Fixation with mini-fragment blade plate augmenting greater tuberosity fixation following bone grafting and cuff sutures



**Fig. 9.70** C-arm positioning for Grashey view



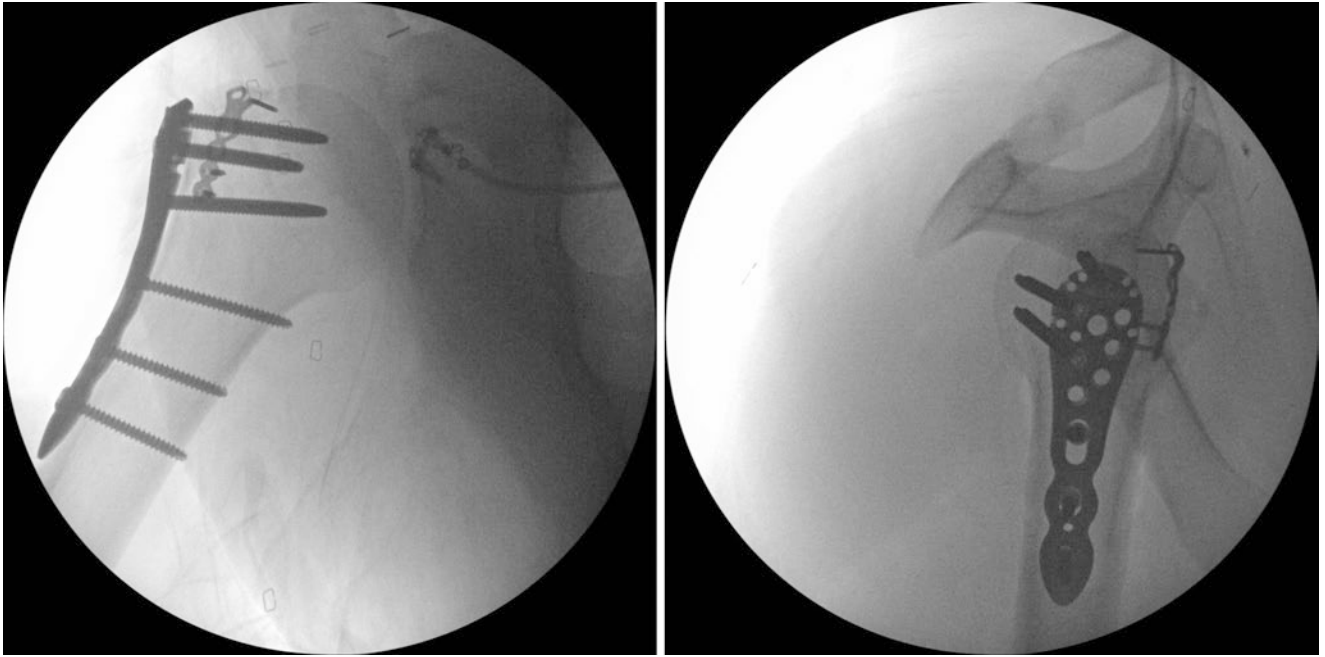
**Fig. 9.71** C-arm positioning for Y-scaphular view



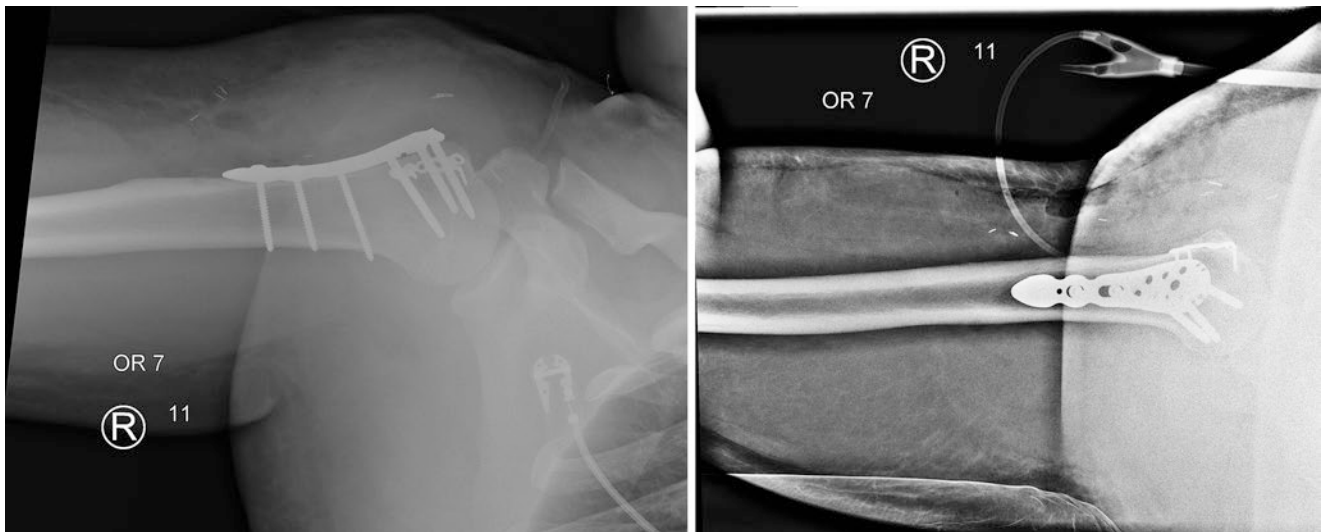
**Fig. 9.72** Arm internally rotated for 90-degree arc sweep to check screw length



**Fig. 9.73** Arm externally rotated at end of rotation. The same sweep would be performed in Grashey view



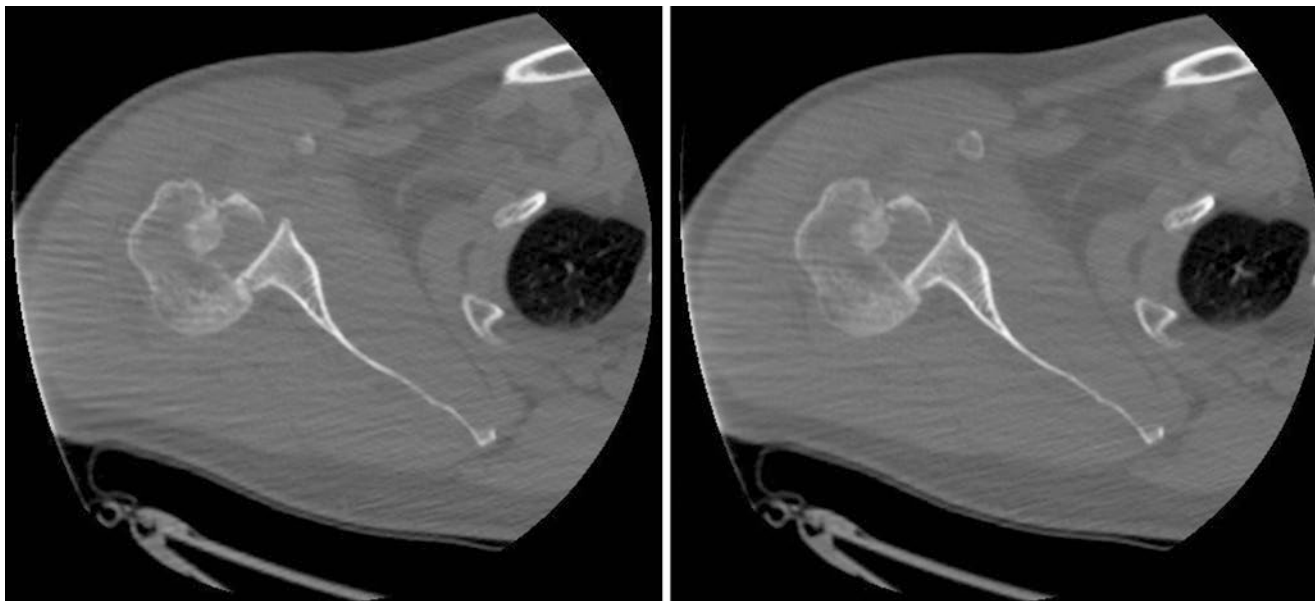
**Fig. 9.74** Intraoperative C-arm radiographs; despite bone grafting, a small defect is visible at the tip of the blade plate



**Fig. 9.75** Postoperative radiographs

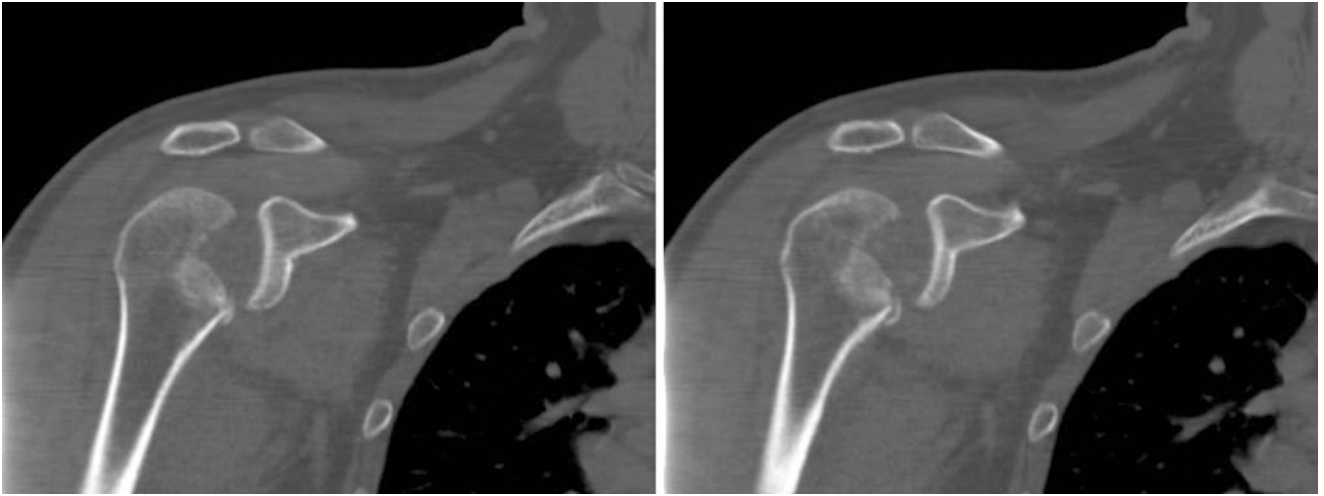
Lesser tuberosity fractures are associated with dislocations, particularly posterior dislocations, and these are addressed with ORIF and plate fixation (Figs. 9.76, 9.77, 9.78, 9.79, and 9.80).

**Fig. 9.76** Radiograph of persistent right shoulder posterior dislocation despite reduction efforts at referral site

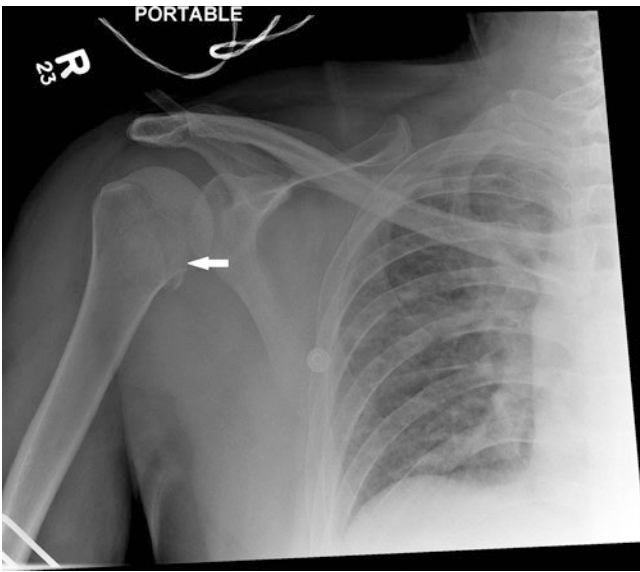


**Fig. 9.77** CT scan demonstrating locked posterior dislocation. (Patient had bilateral dislocations following seizures)

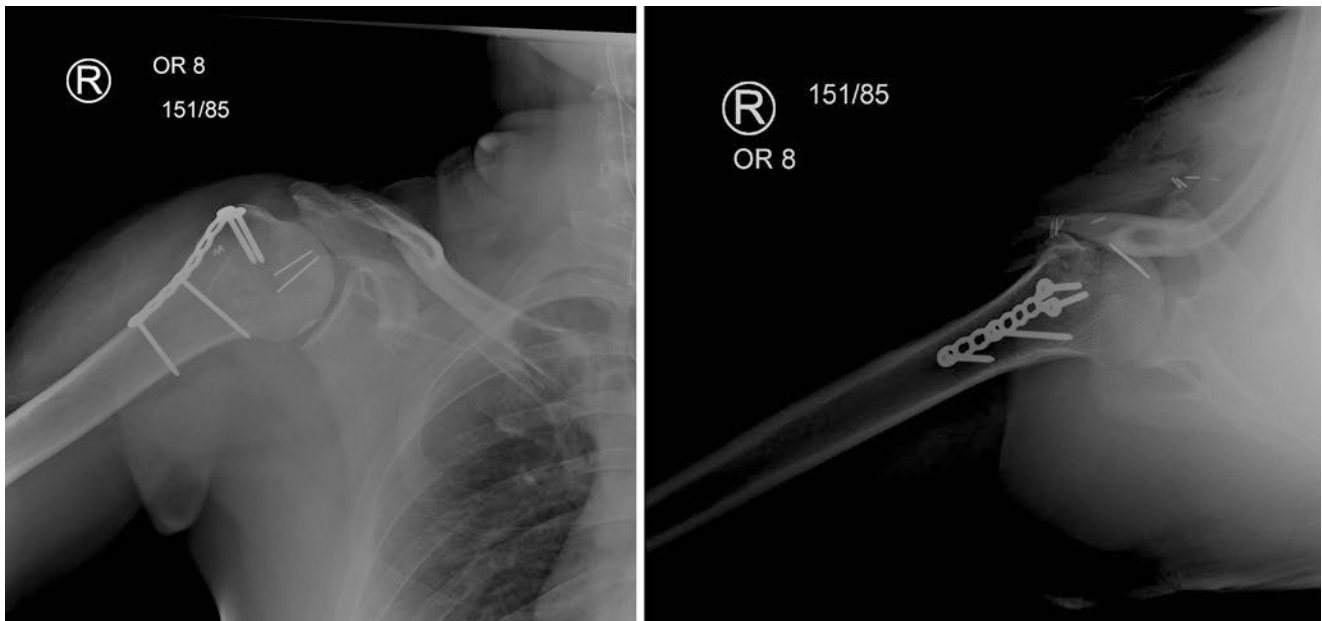




**Fig. 9.78** Coronal views showing large head defect



**Fig. 9.79** Radiograph following reduction with displaced lesser tuberosity fracture (*arrow*)



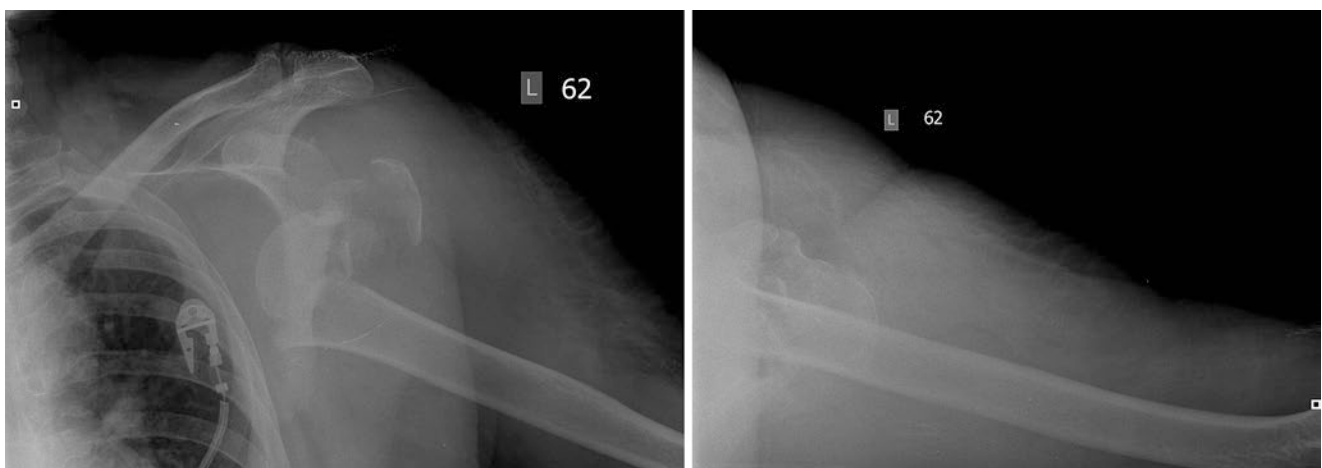
**Fig. 9.80** Intraoperative radiographs following open reduction and internal fixation (ORIF) of the lesser tuberosity fracture, which extended laterally

ORIF for both isolated greater and lesser tuberosity fractures is performed with cuff repairs.

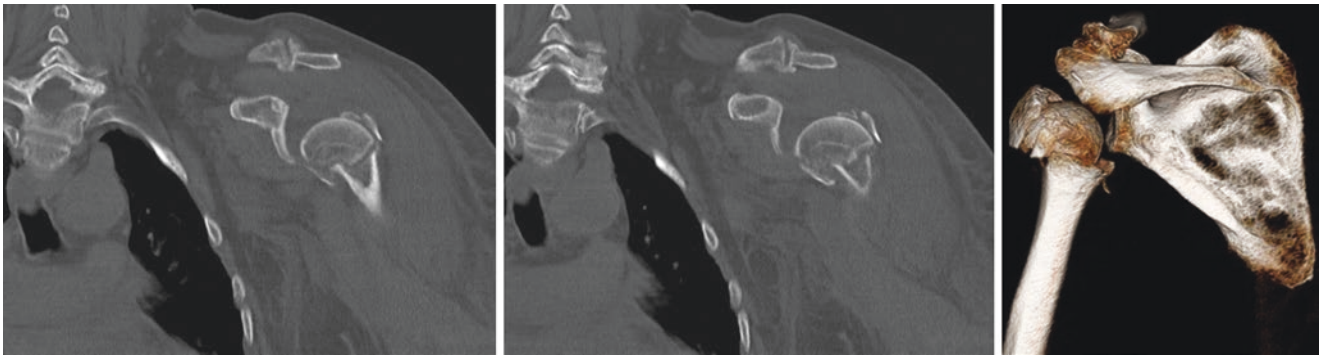
### 9.2.2 Case Examples: Valgus Impacted Fractures

Valgus impacted fractures are the variety more commonly associated with tuberosity displacement and bone impaction. They tend to encompass the three- and four-part fractures, but fracture dislocations also can be three- and four-part.

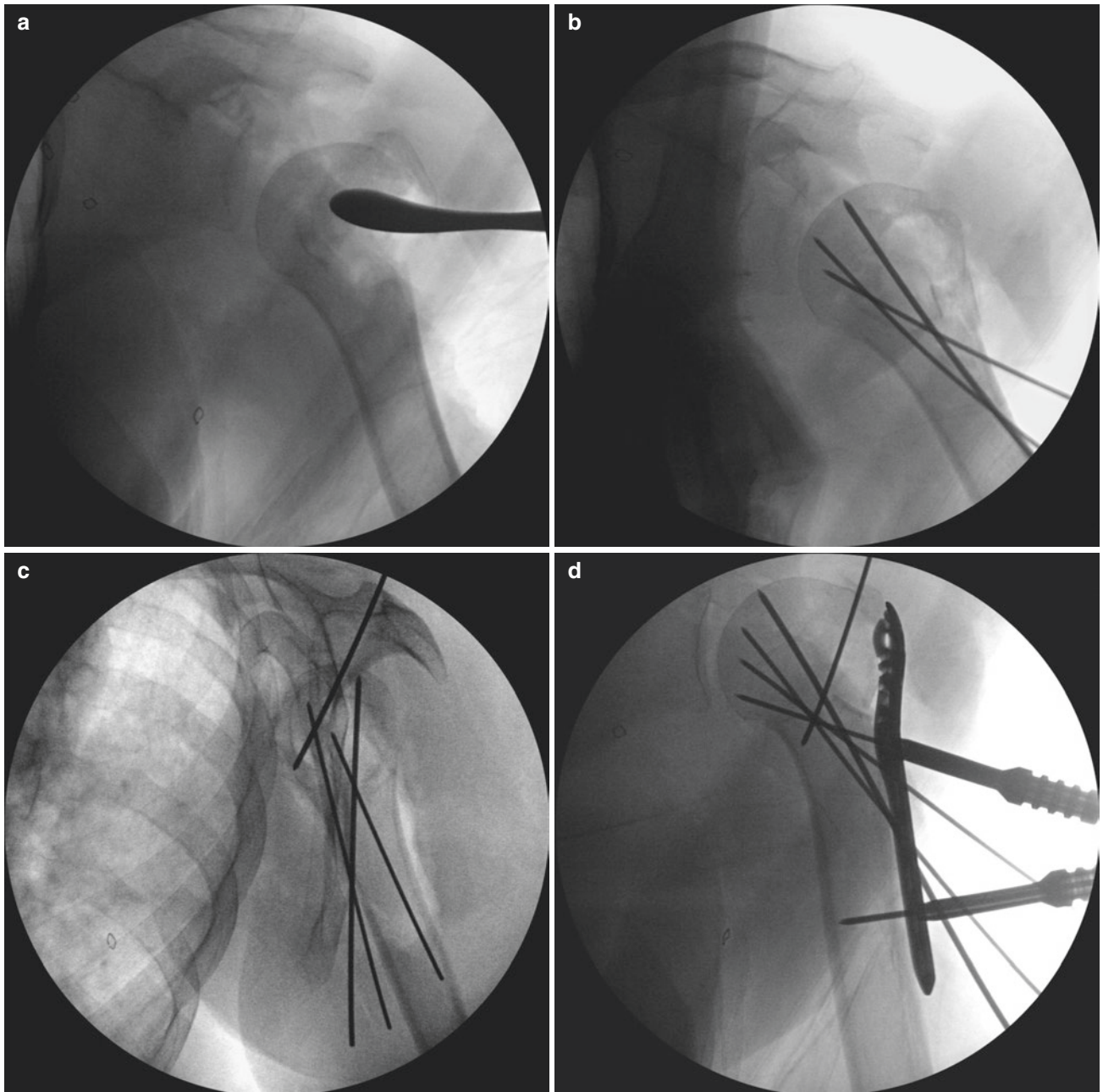
Commonly, on approach the humeral head is seen facing laterally or in a superior fashion. If there is a tear in the cuff, and it is not always in the supraspinatus/glenohumeral ligament and subscapularis interval, it allows a view of or access to the joint and the relationship to the other fragment to judge the reduction. Preserving the medial hinge is critical, and your first reduction is your best, so once you prepare for reducing, make sure your K-wires are ready to secure the neck to the head (Figs. 9.81, 9.82, and 9.83).



**Fig. 9.81** Radiographs of left proximal humeral fracture dislocation



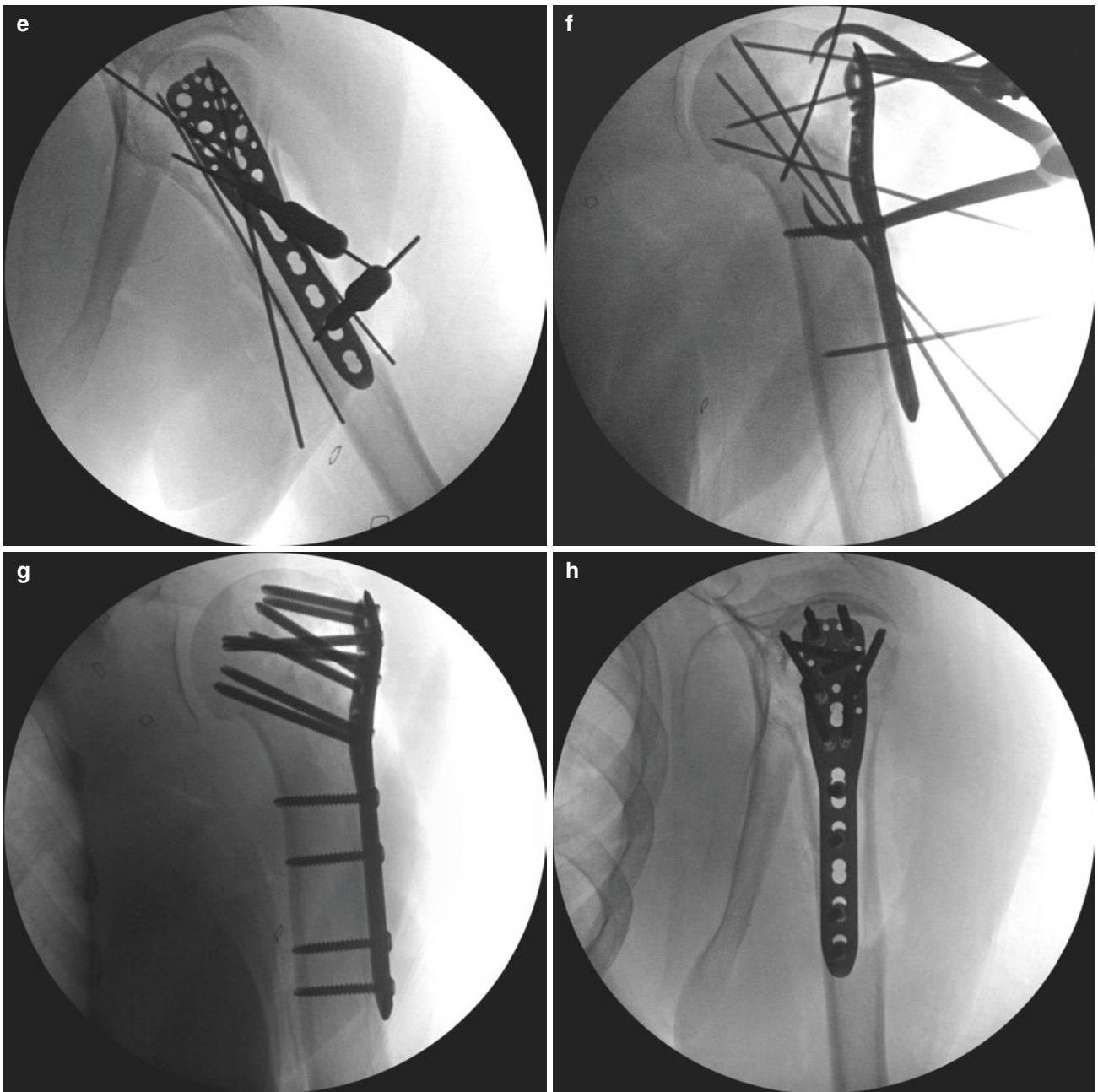
**Fig. 9.82** CT scan demonstrating valgus impaction



**Fig. 9.83** (a) Head reduced with Cobb elevator. (b, c) Provisional K-wire fixation. (d) Preliminary plate positioning after bone grafting. (e) Y-scapular view checking plate positioning. (f) First screw inserted

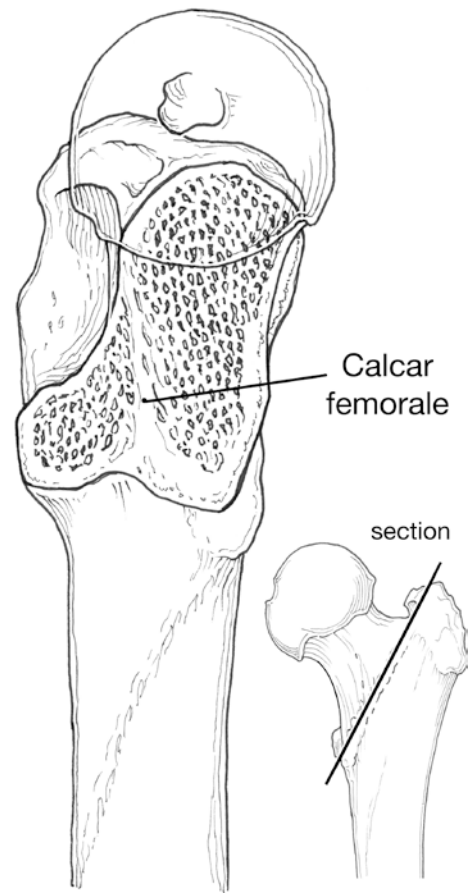
in the plate in the shaft to afford graft impaction in the head. (g) Grashey C-arm view following completion of fixation. (h) Y-scapular view





**Fig. 9.83** (continued)

In the acute scenario, I do not use the intramedullary fibula technique, though I do use intramedullary fibulas, particularly in nonunion situations. I don't know that I have seen a case in which the cancellous bone impacted didn't fit the need and in which the fibula would have improved stability or fixation. There also have been a number of discussions concerning the use of a calcar screw to support or secure the medial humeral neck. I take exception to the term *calcar*, which has been misleadingly hijacked from the proximal femur. *Calcar* means spur, and the *calcar femorale* is actually a projection in the femoral canal from a phylogenetic process, not the medial femoral neck in the posteromedial region (Fig. 9.84).

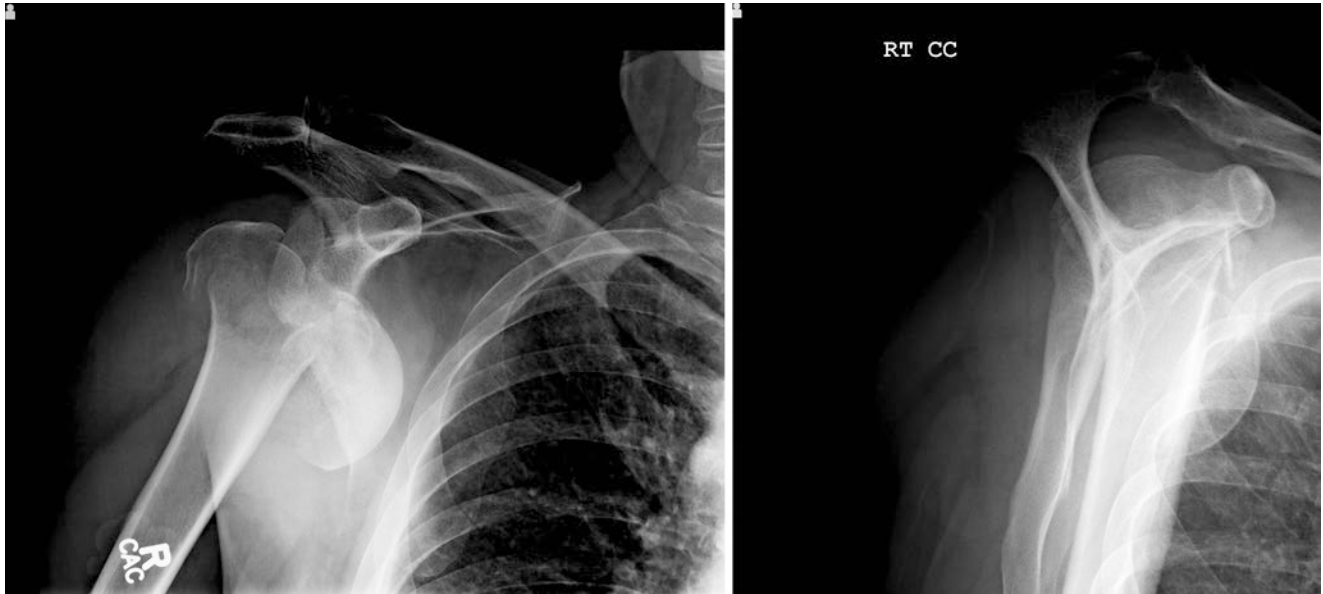


**Fig. 9.84** Diagram of calcar femorale projection off the medial neck into the canal

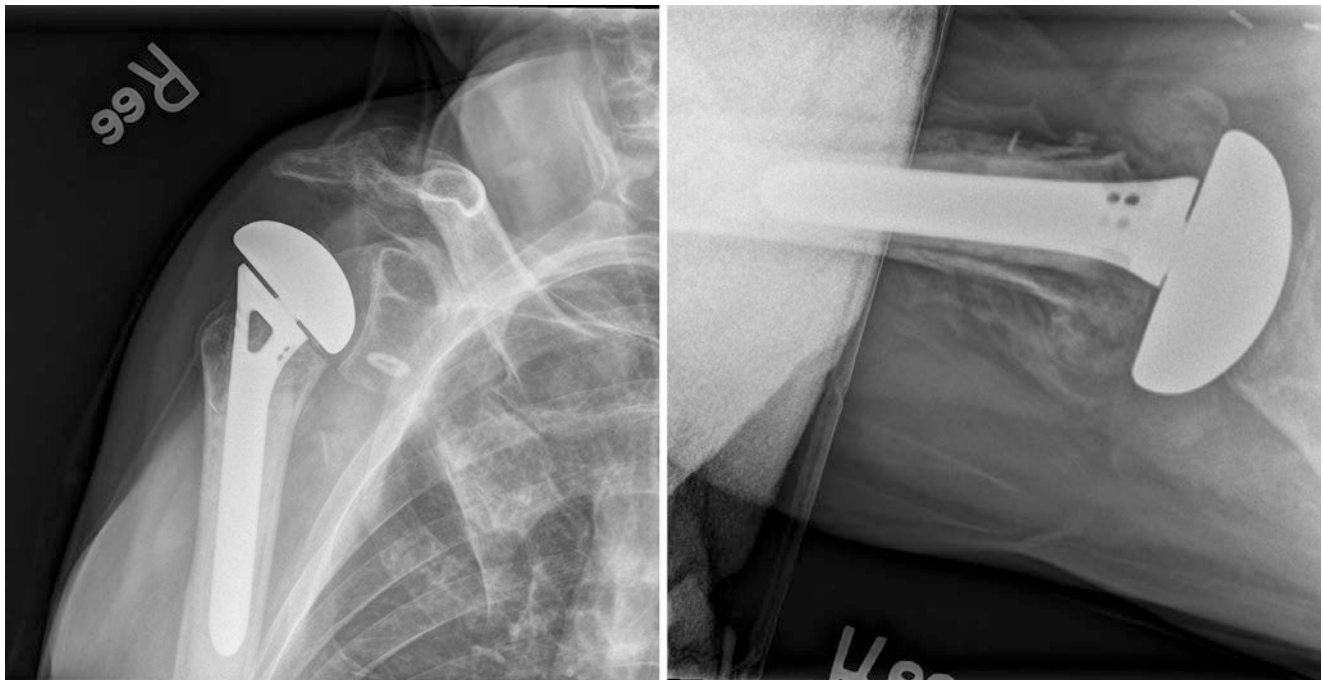
There is no equivalent in the proximal humerus. A kickstand screw may have utility in fixation, but I feel that the more superior screws in your locked plate construct are more appropriate, particularly in a varus angulation scenario.

ORIF has been performed for fracture dislocations and “bad” three- and four-part valgus fractures, as has hemiarthroplasty and total or reverse total arthroplasties.

Hemiarthroplasties are rarely performed, as I find the results are generally poor (Figs. 9.85 and 9.86).



**Fig. 9.85** Radiographs of right proximal humeral fracture dislocation with head deemed not amenable to fixation



**Fig. 9.86** Radiographs following hemiarthroplasty



I have not performed and will not perform either total or reverse total arthroplasties; I refer these cases to the “Pros from Dover.” In the older population, the reverse shoulder

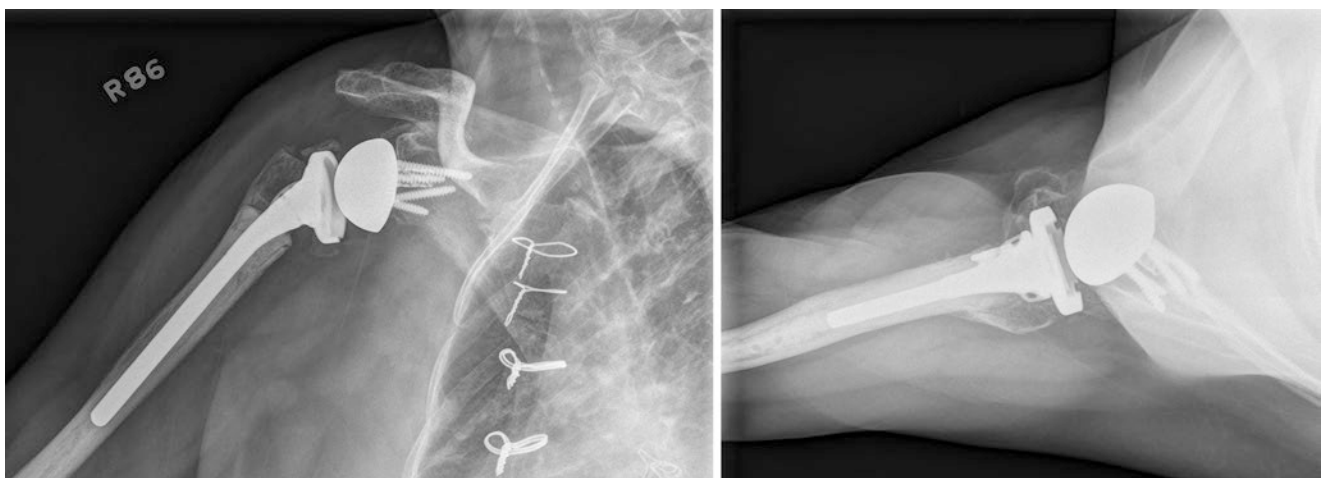
arthroplasty has shown promise, outperforming hemiarthroplasty [20] (Figs. 9.87, 9.88, and 9.89).



**Fig. 9.87** Injury radiographs of right proximal humeral fracture in patient with known pre-existing rotator cuff deficit



**Fig. 9.88** CT scan of right shoulder demonstrating poor bone quality



**Fig. 9.89** Radiographs following reverse shoulder arthroplasty

Soliman and Koptan [35] prospectively reviewed four-part fracture dislocations with functional results attained with ORIF, despite some avascular necrosis (AVN) and collapse. A technique I use for fracture dislocations when there is concern for subsequent collapse is this: Park the screws close to the subchondral bone, realizing that collapse may occur. I counsel the patient that a

second operation may be required at 6–9 months if collapse begins. When that second operation is needed, I remove the plate, impact cancellous bone graft (usually allograft), and occasionally replace the plate using shorter screws. If enough healing has occurred, I may forgo any implants (Figs. 9.90, 9.91, 9.92, 9.93, 9.94, 9.95, 9.96, 9.97, and 9.98).



**Fig. 9.90** Radiographs of left proximal humeral valgus impacted fracture



**Fig. 9.91** Radiographs following ORIF



**Fig. 9.92** One-week follow-up



**Fig. 9.93** Three-month postoperative follow-up



**Fig. 9.94** Six-month postoperative follow-up, with decreasing distance from screw to subchondral bone

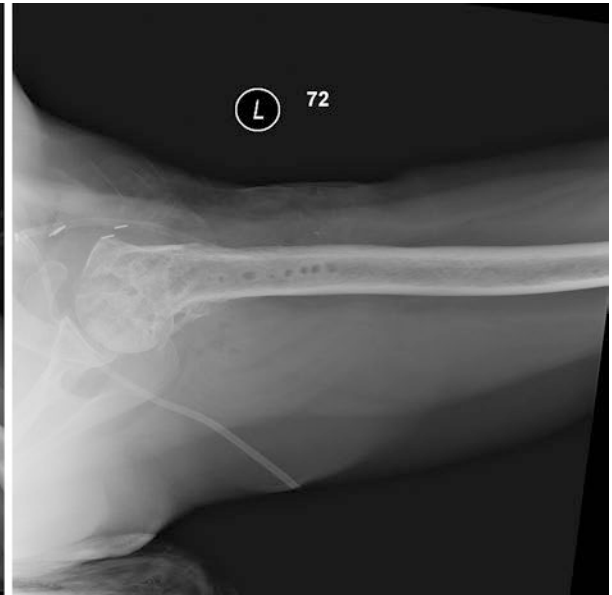




**Fig. 9.95** Nine-month postoperative follow-up, with further head collapse



**Fig. 9.96** One-year postoperative follow-up, with screw protrusion



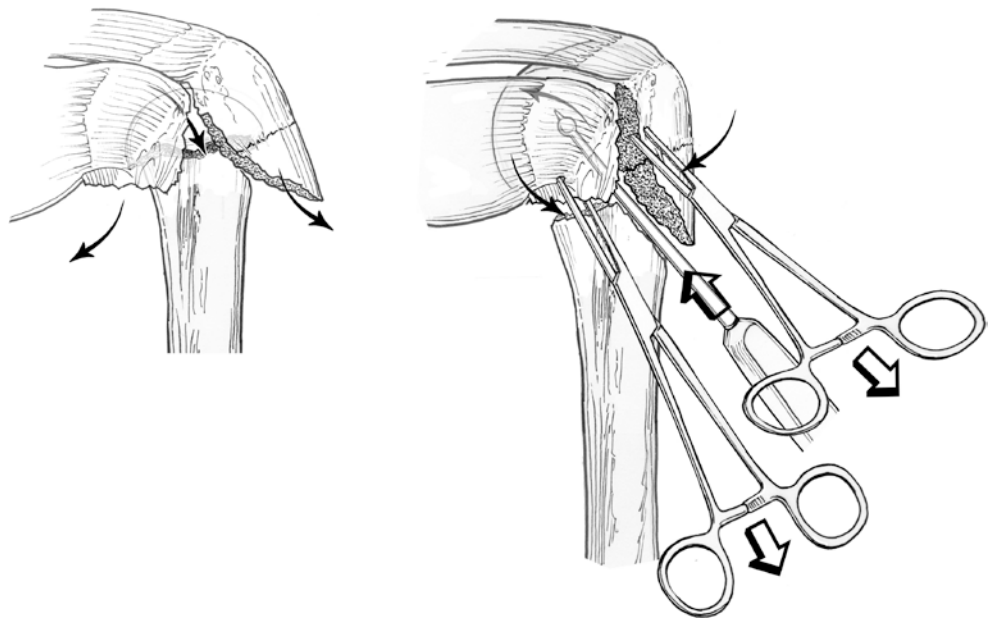
**Fig. 9.97** Radiographs 13 months after initial surgery, with hardware removal and impaction bone grafting in screw holes



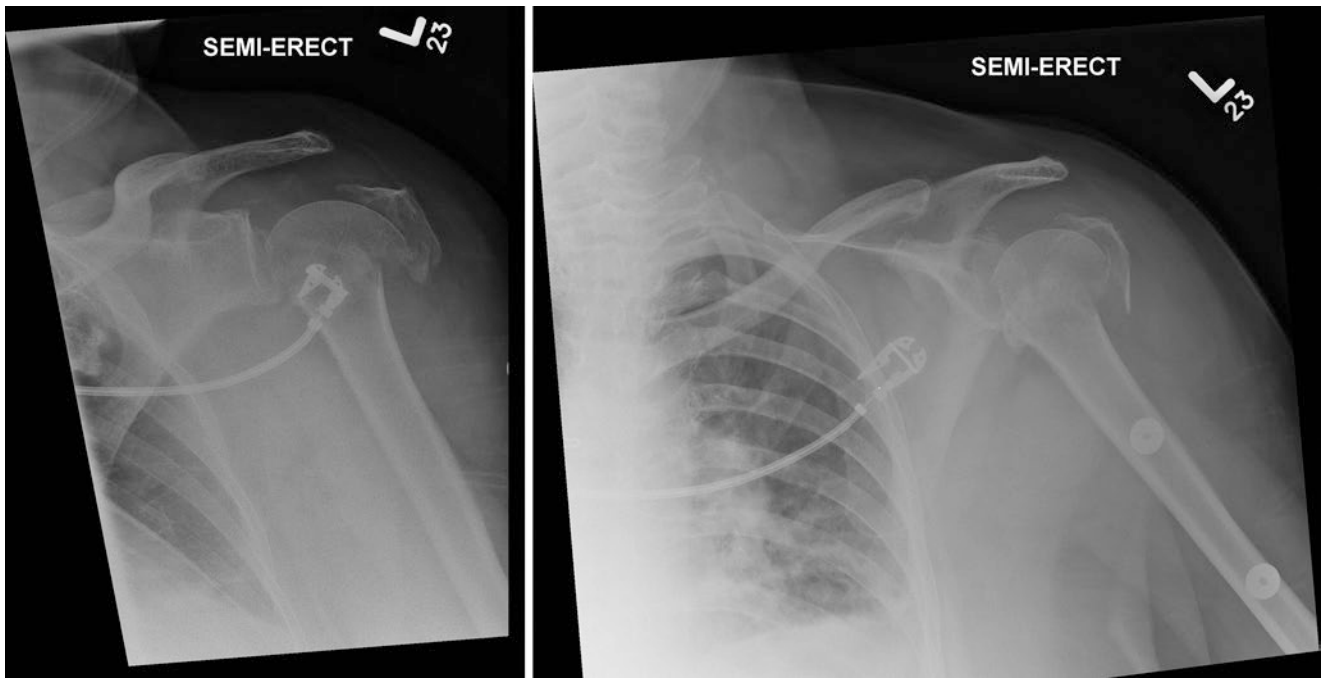
**Fig. 9.98** Follow-up 2 years after initial surgery, with avascular necrosis and head collapse—yet the patient was functioning without limitations

In valgus impaction fractures, after the approach has been performed, I control the greater and lesser tuberosities, usually with Kocher clamps. I prefer not to place the cuff sutures at that time because they can become entangled, will frequently pull out, and generally get in the way. A ball tip pusher is used to push the humeral head out of valgus, as the

greater tuberosity and lesser tuberosity fragments are tensioned laterally. The head is then generally stabilized to the proximal shaft with a 5/64 Steinmann pin; it usually takes two pins to prevent rotation (Figs. 9.99, 9.100, 9.101, 9.102, 9.103, 9.104, 9.105, and 9.106).



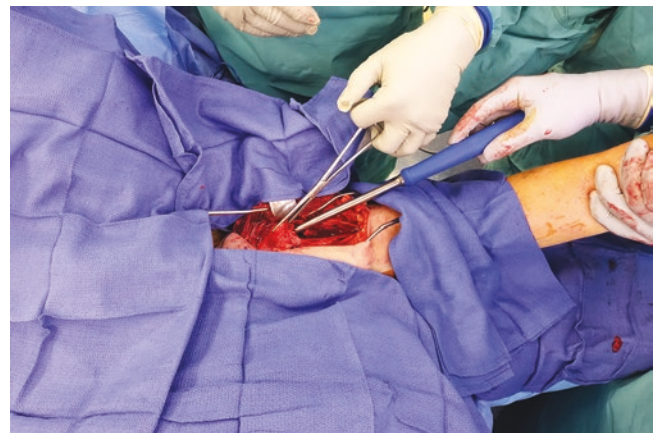
**Fig. 9.99** Diagrammatic representation of maneuver to reduce a valgus impacted humeral head with Kochers and a ball tip pusher



**Fig. 9.100** Injury radiographs of valgus impacted left proximal humeral fracture (contralateral shoulder of patient in Fig. 9.87)

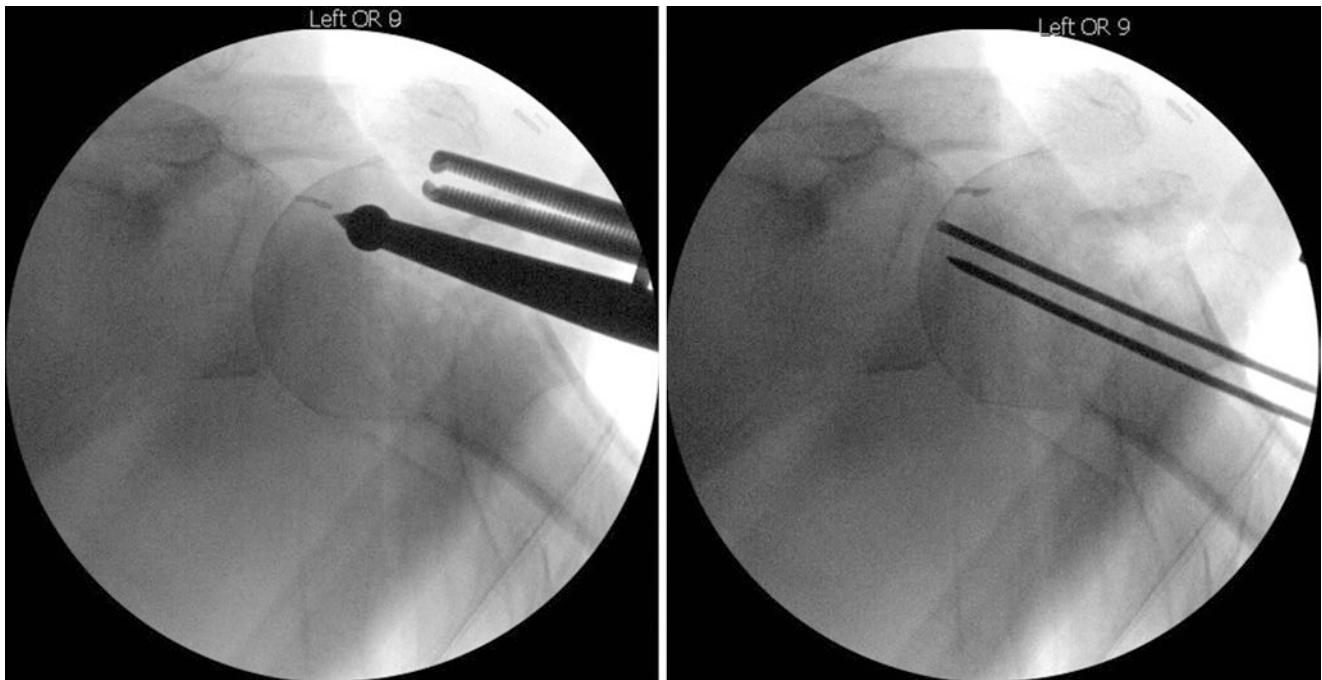


**Fig. 9.101** Intraoperative exposure with head visualized through rotator cuff tear

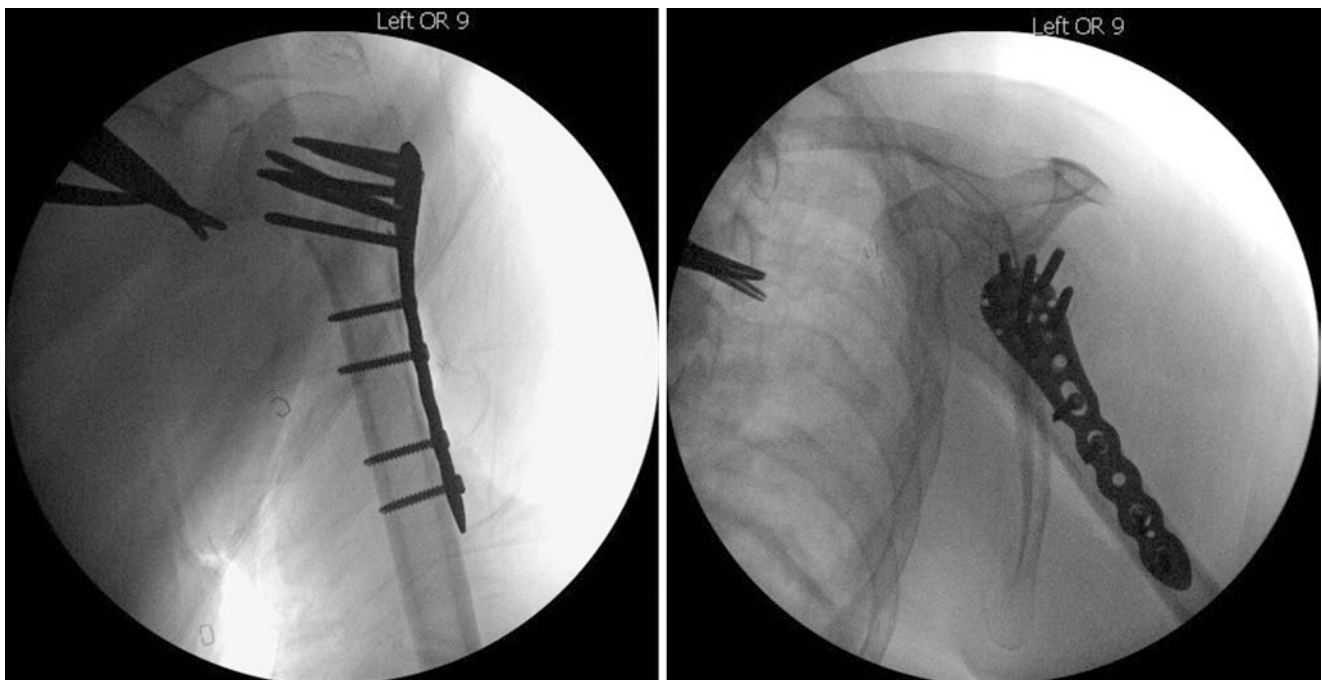


**Fig. 9.102** Reduction maneuver with Kocher and ball tip pusher



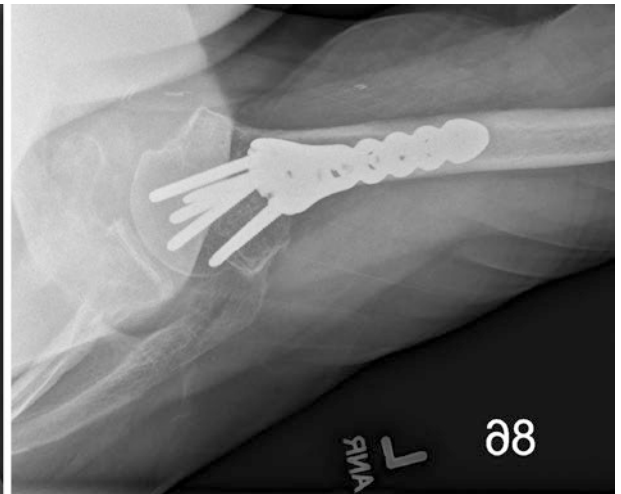
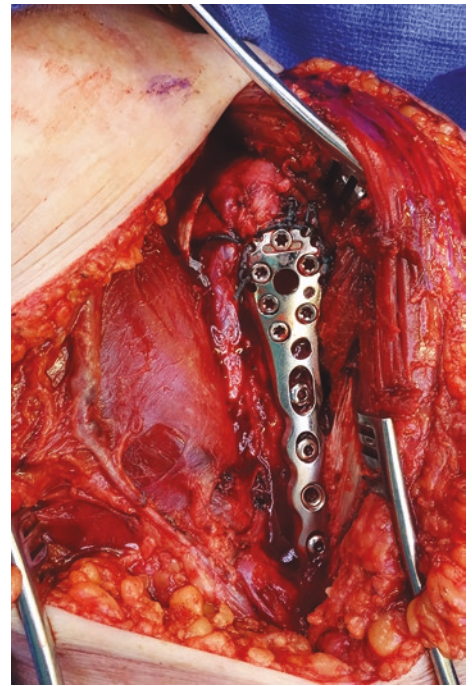


**Fig. 9.103** Radiographs of position attained and provisional fixation



**Fig. 9.104** Final intraoperative C-arm radiographs

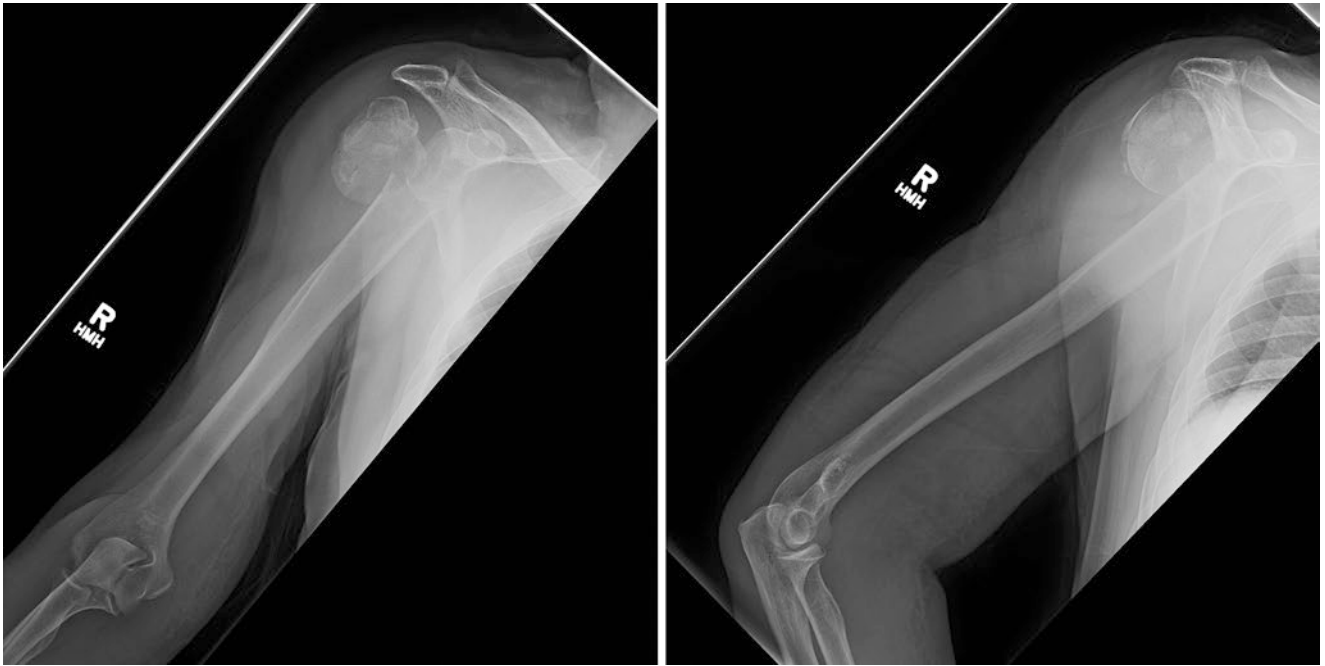
**Fig. 9.105** Final fixation, including rotator cuff sutures tied



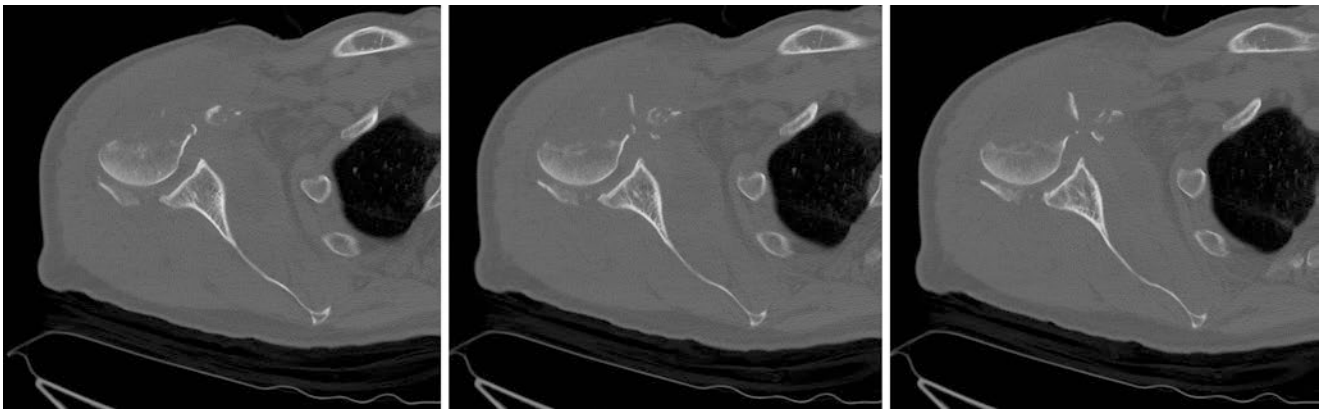
**Fig. 9.106** Final follow-up radiographs. Four months following surgery, the patient had returned to using the arm to throw horseshoes

Occasionally the head will be pinned to the glenoid first and tuberosities, and then the shaft is reduced to the head. This technique requires a lot of holding without motion, so

as not to propagate fractures or pull apart fixation (Figs. 9.107, 9.108, 9.109, and 9.110).



**Fig. 9.107** Radiographs of right proximal humeral fracture with head rotation and neck shaft displacement



**Fig. 9.108** CT scan demonstrating extent of head involvement



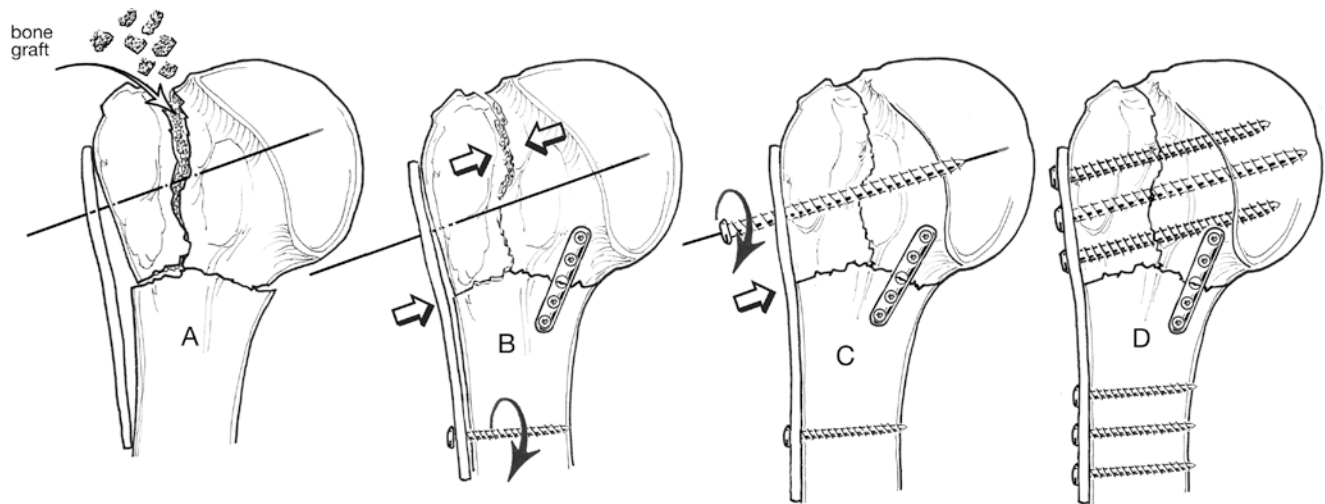


**Fig. 9.109** Coronal CT scan demonstrating significant head preservation to consider ORIF



**Fig. 9.110** Technique of head fixation into the glenoid, followed by reduction of other fragments to the stabilized head

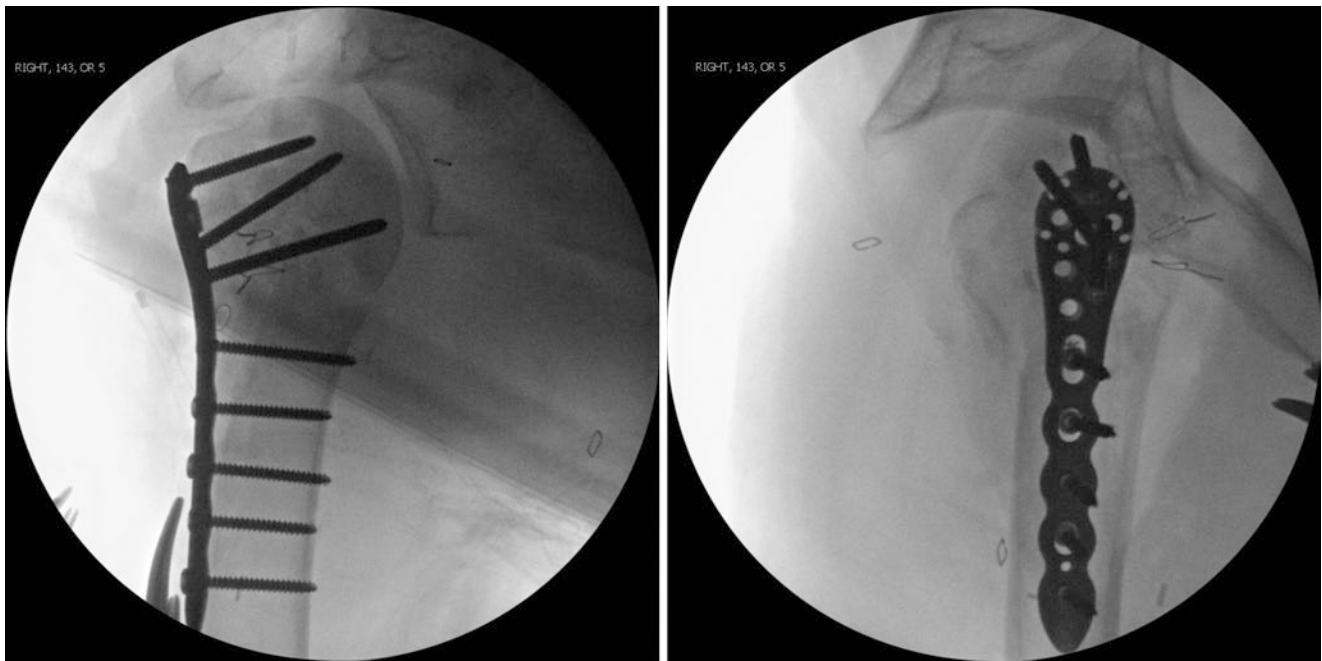
With stabilization of the head, I use the C-arm (more so than direct visualization) to evaluate reduction, in an effort to preserve as much soft tissue support to the fracture fragments as possible. The lesser and greater tuberosities are then reduced. There are frequent keys, particularly in the lesser tuberosity, such that a mini-plate or some form of limited internal fixation could be performed in the bicipital groove. At this point I insert #5 Ethibond® sutures. Prior to the fixation of the greater tuberosity, cancellous allograft bone graft is impacted; I actually overstuff the bone graft so that the subsequent plate fixation essentially compresses the bone graft. The greater tuberosity is reduced and held with a K-wire. After the Ethibond® sutures are placed through the holes in the plate of choice, the plate is positioned. I generally start with a cortical screw down the shaft, in an effort to apply some degree of compression to the cancellous bone graft. I generally like to use three or four screws down the shaft and four or five screws in the head, depending on the fracture and the bone quality (Figs. 9.111, 9.112, 9.113, and 9.114).



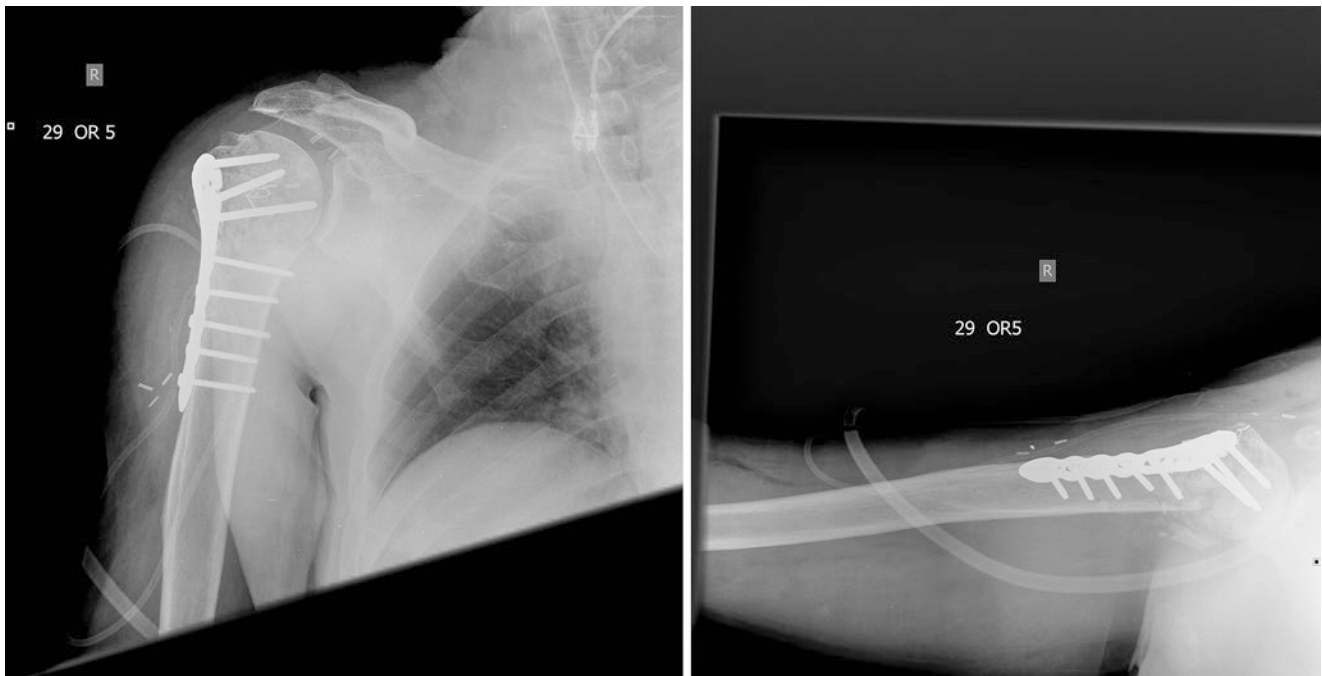
**Fig. 9.111** Diagrammatic representation of steps in fixation and bone grafting for a valgus impacted or displaced humeral head. The shaft screw is inserted after the bone graft is inserted to impact the graft. (a–d) denote sequence of fixation



**Fig. 9.112** Another technique to impact the graft is to use a centering screw in the head, as in this case, followed by locking screws and delivering the shaft to the plate with a cortical screw down the shaft



**Fig. 9.113** Final intraoperative C-arm radiographs



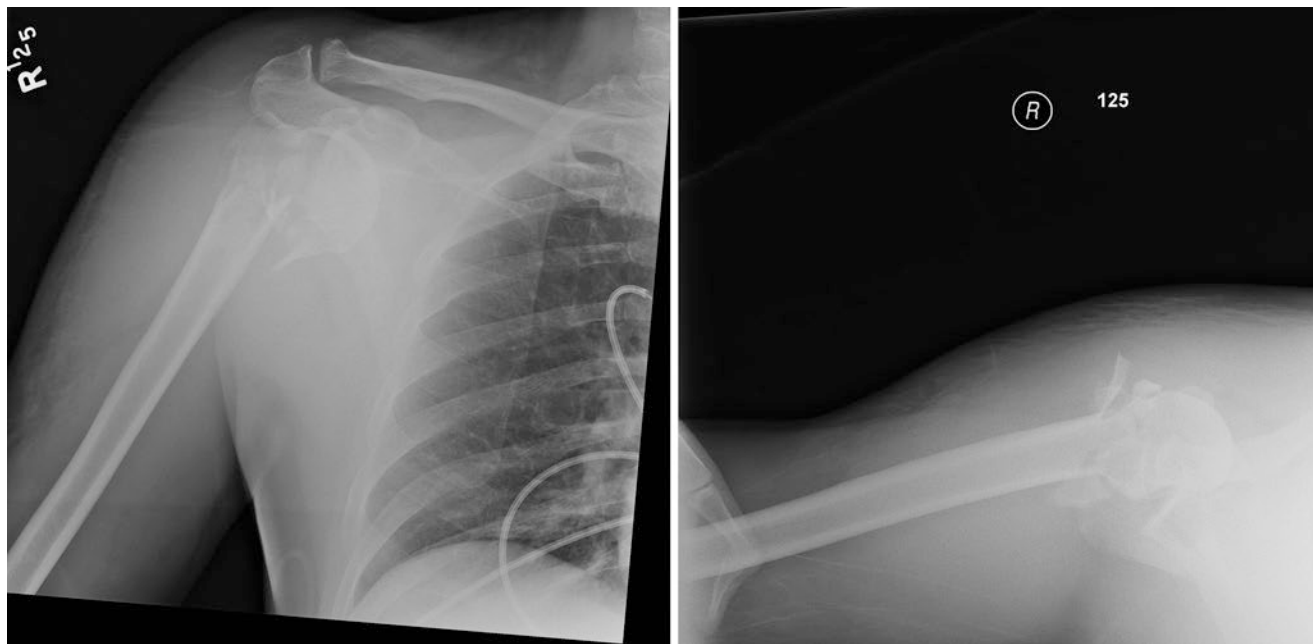
**Fig. 9.114** Postoperative radiographs, Grashey and axillary views



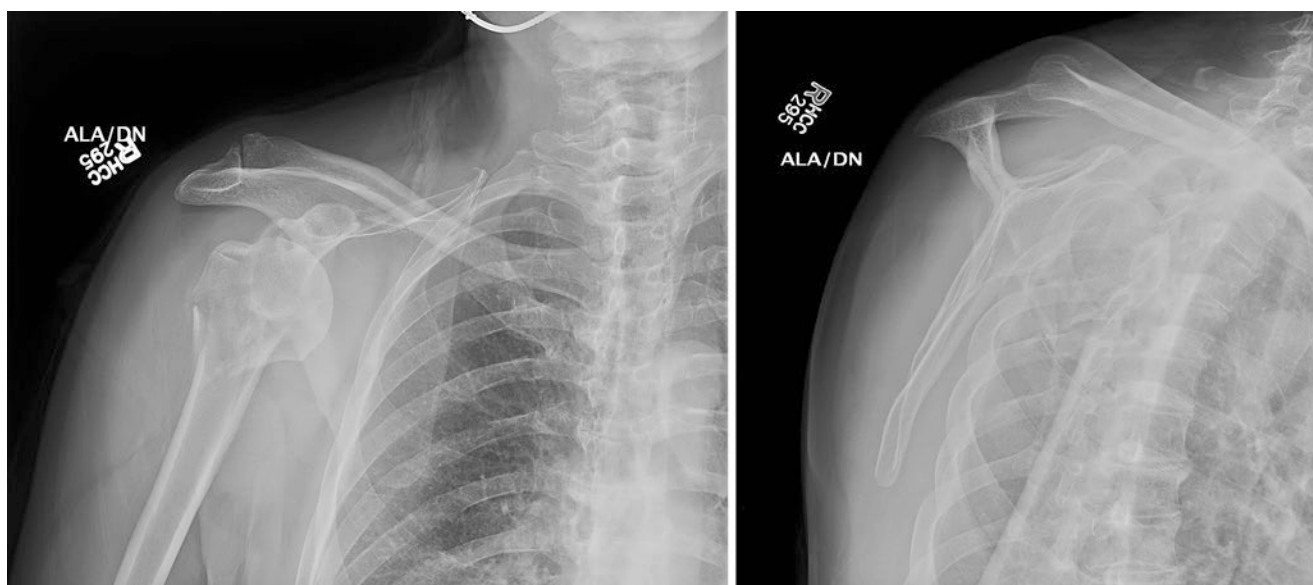
### 9.2.3 Case Examples: Fracture Dislocations

Fracture dislocations pose special problems, even though the ultimate fixation is similar to that which has been presented. If the head is still attached to the neck and shaft in either an anterior or posterior dislocation, you must be careful to prevent fracturing or displacing the neck during reduction. Such fracture may be successfully treated with ORIF and not replaced. Following are potentially helpful steps in the reduction of the anterior and posterior dislocations.

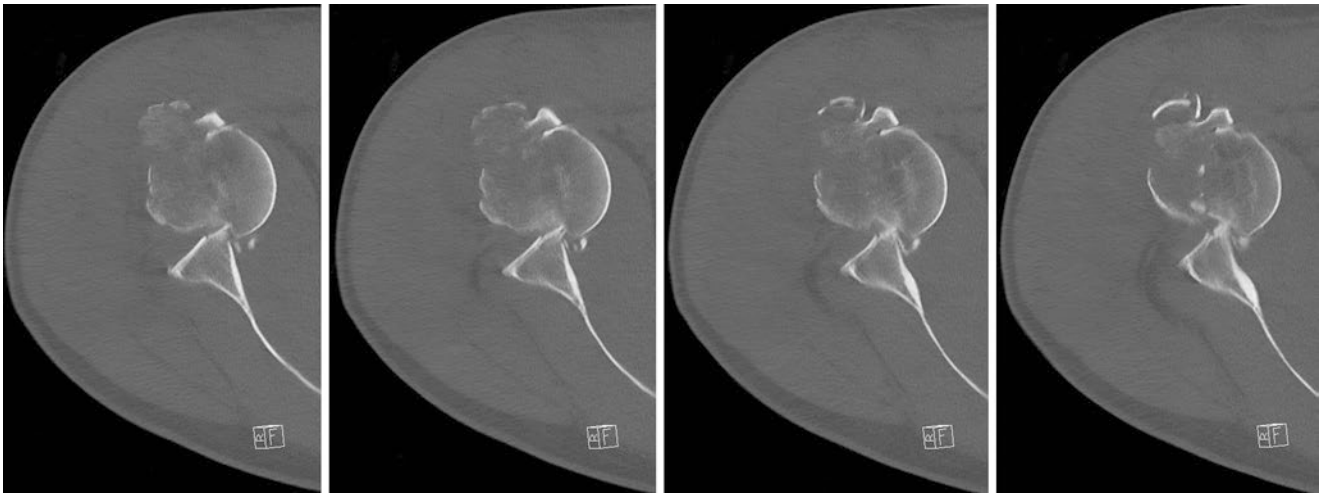
With either anterior or posterior dislocation, there is the tendency to initiate reduction with traction, and if that doesn't work, to pull harder. With an anterior dislocation, disengaging the head is needed as a first maneuver, but to gain access to the head, a coracoid osteotomy may be required. Once the head can be reached, it must be disengaged from the anterior rim of the glenoid, followed by lateralizing and traction (Figs. 9.115, 9.116, 9.117, 9.118, 9.119, 9.120, 9.121, 9.122, 9.123, 9.124, 9.125, 9.126, 9.127, 9.128, 9.129, 9.130, 9.131, 9.132, 9.133, 9.134, 9.135, 9.136, 9.137, 9.138, and 9.139).



**Fig. 9.115** Injury radiographs of right proximal humeral anterior fracture dislocation

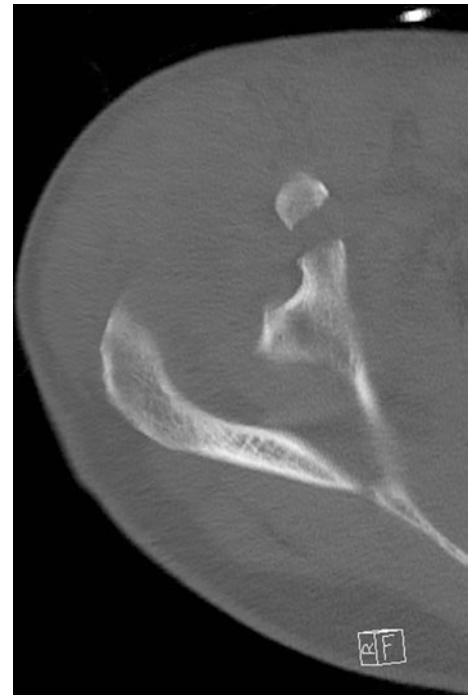


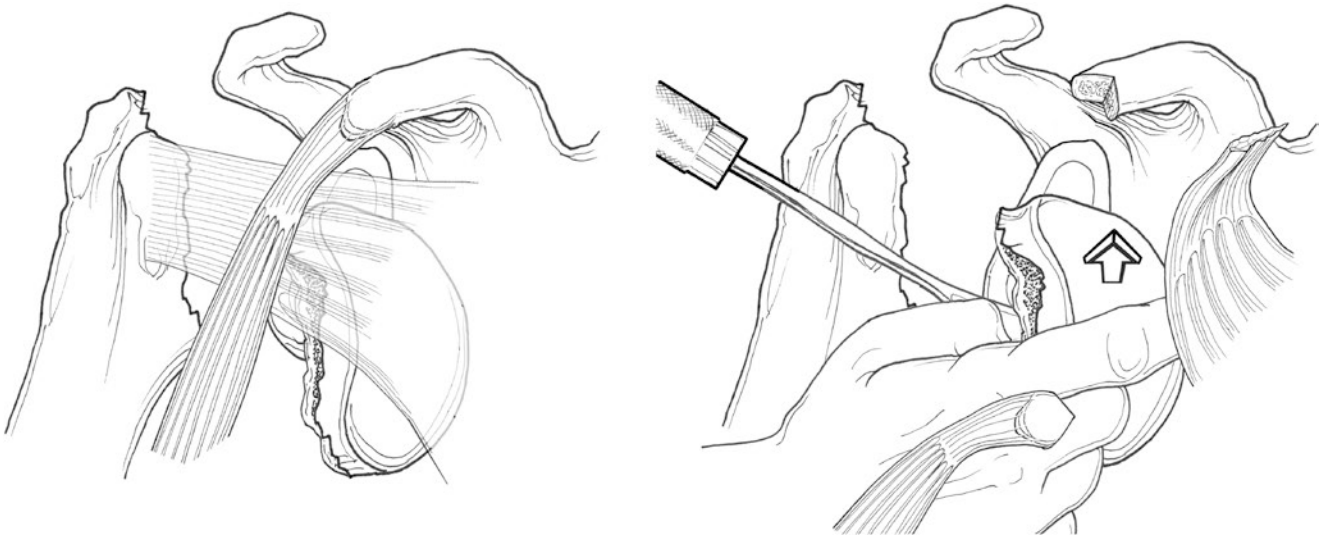
**Fig. 9.116** Dedicated shoulder radiographs demonstrating the displacement



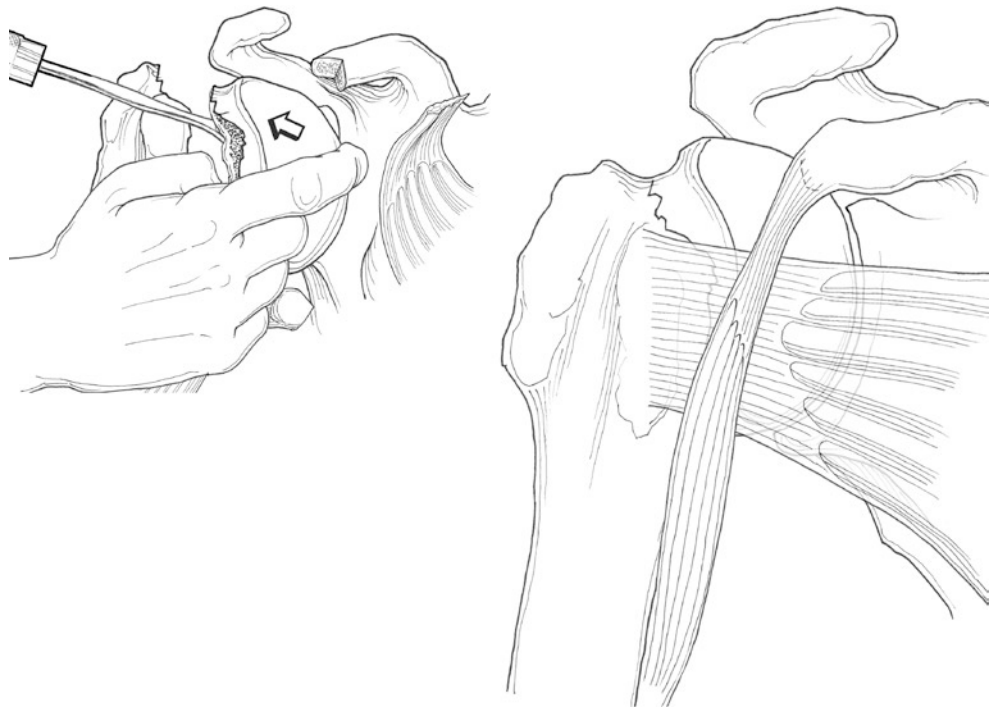
**Fig. 9.117** CT scan revealing the locked, displaced anterior head

**Fig. 9.118** CT scan showing the coracoid fracture, which will be used to gain access to the humeral head





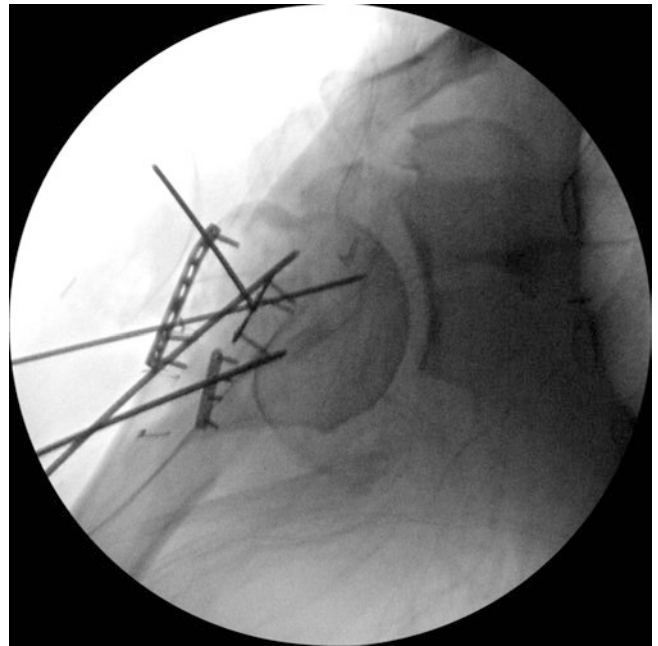
**Fig. 9.119** Diagrammatic steps taken to reduce the anterior dislocated head through a coracoid osteotomy with the use of a Cobb elevator to lift or “shoehorn” the head off of the glenoid



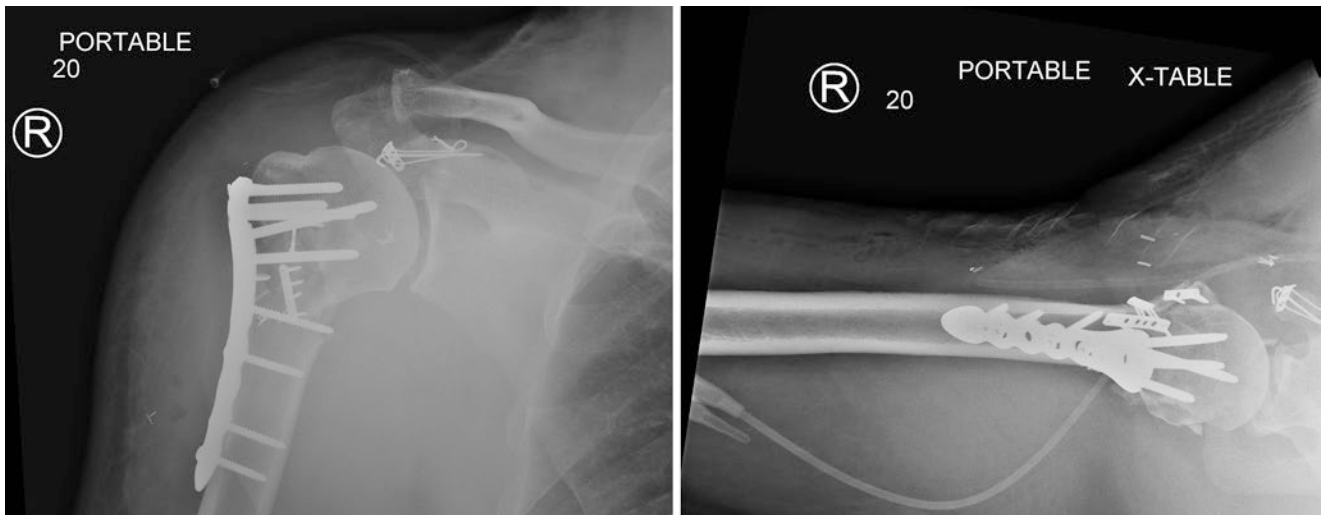
**Fig. 9.120** The head is lateralized, then reduced; proximal humeral fixation and coracoid osteotomy or fracture fixation then follow



**Fig. 9.121** Intraoperative C-arm radiograph of provisional fixation with K-wires and mini-fragment plates



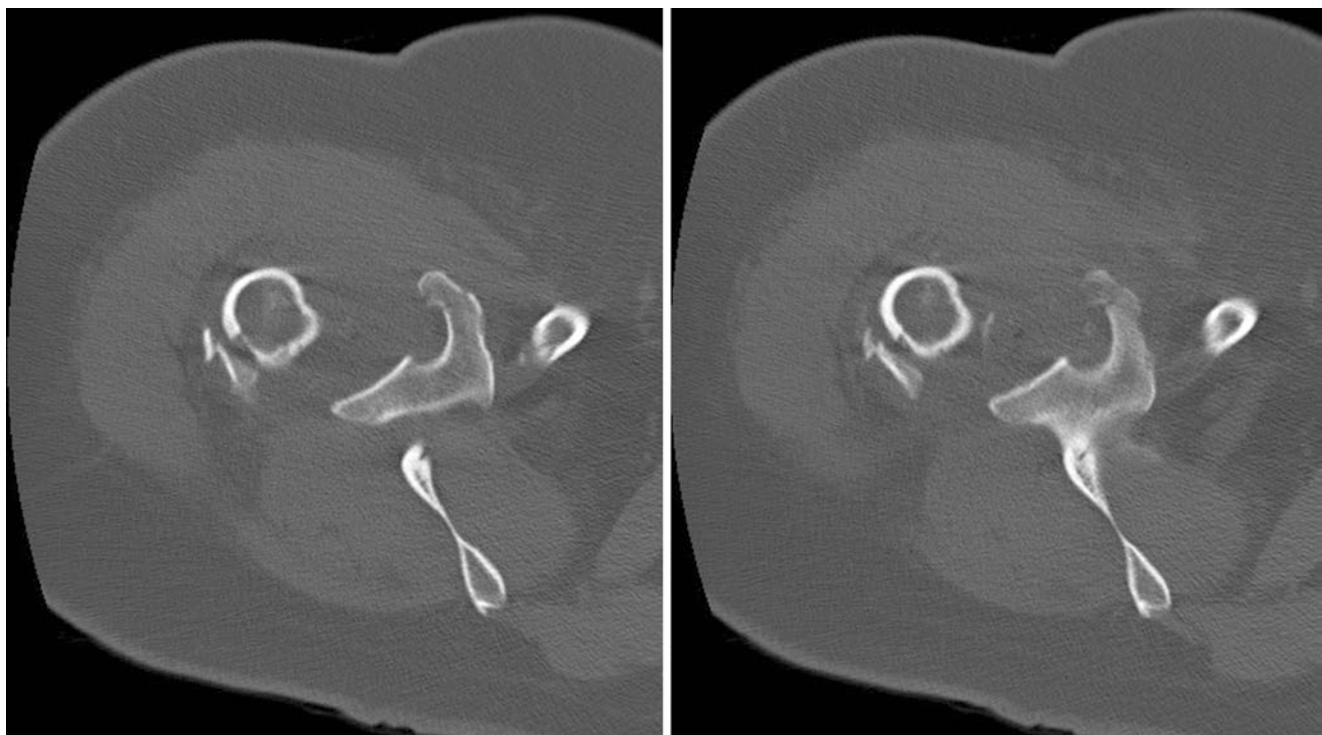
**Fig. 9.122** Intra-operative C-arm radiographs following ORIF, including coracoid fracture



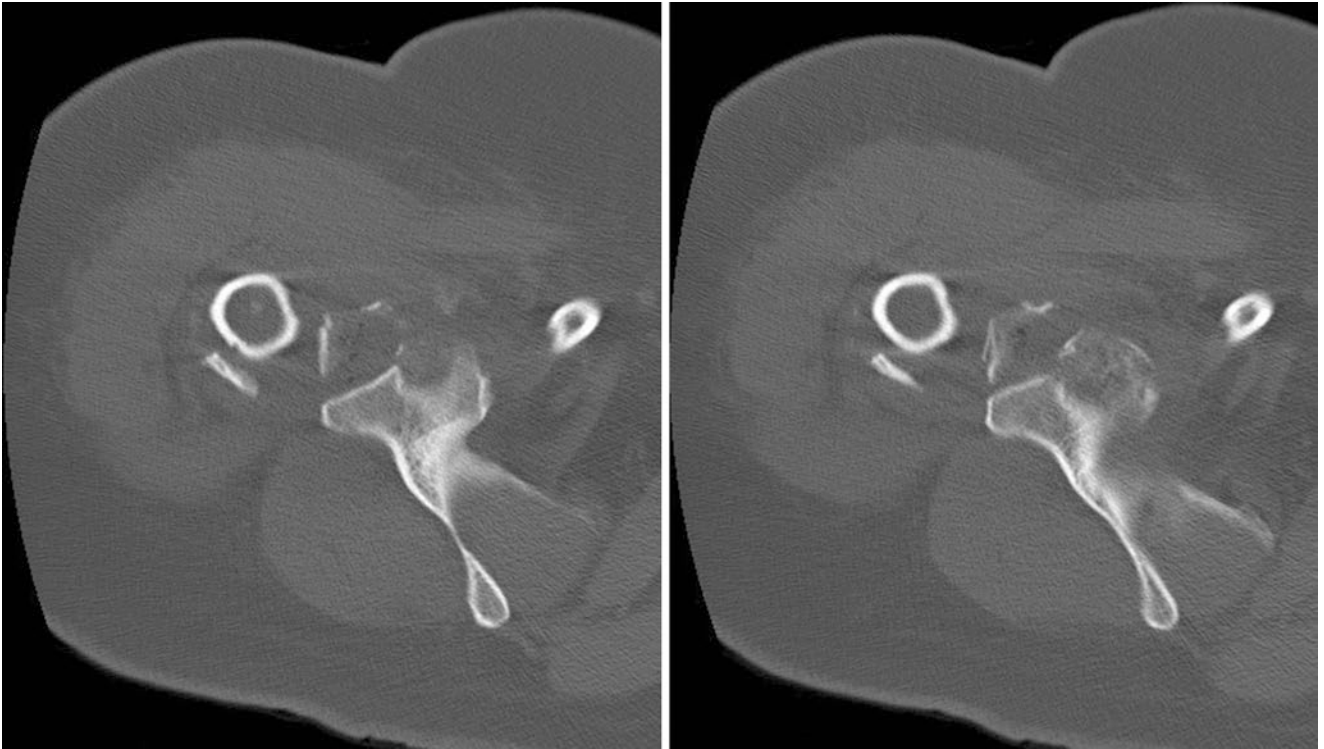
**Fig. 9.123** Postoperative radiographs



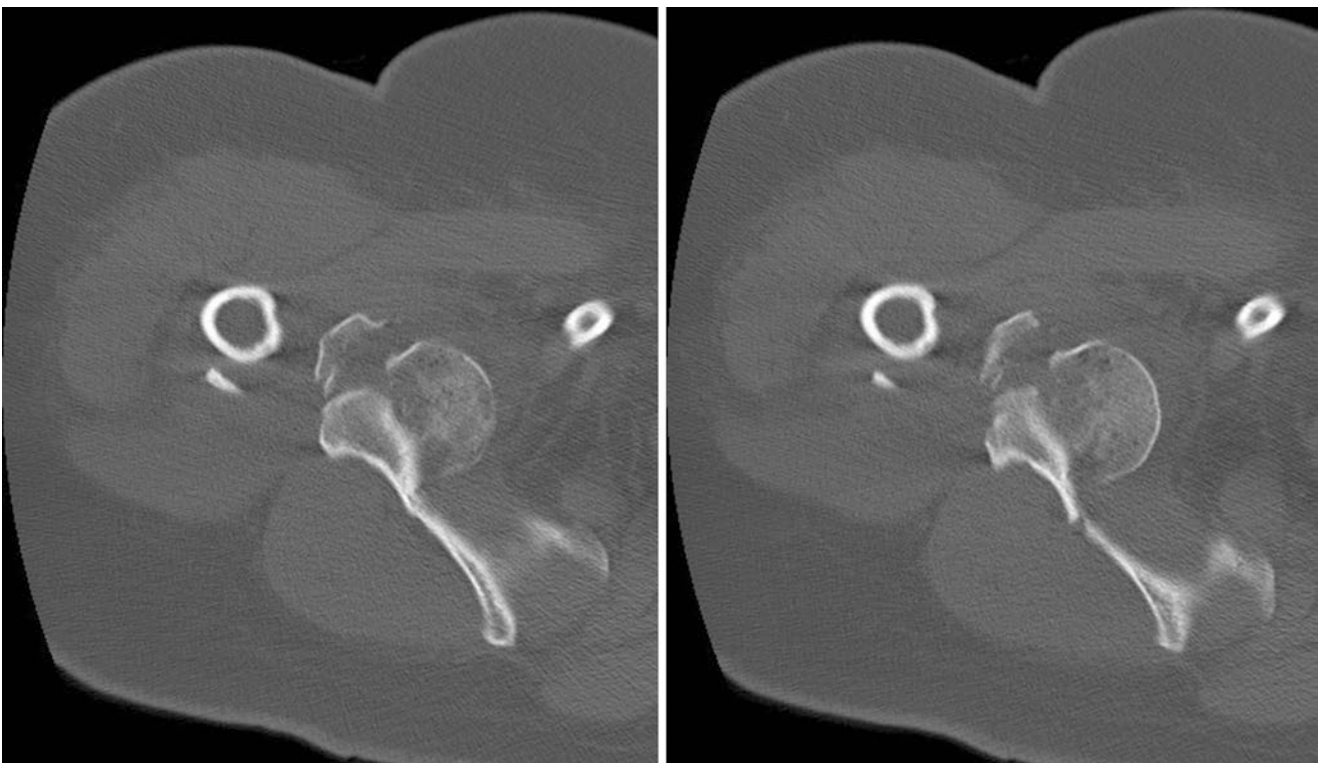
**Fig. 9.124** Radiographs of right proximal humeral anterior fracture dislocation



**Fig. 9.125** CT scan demonstrating coracoid fracture

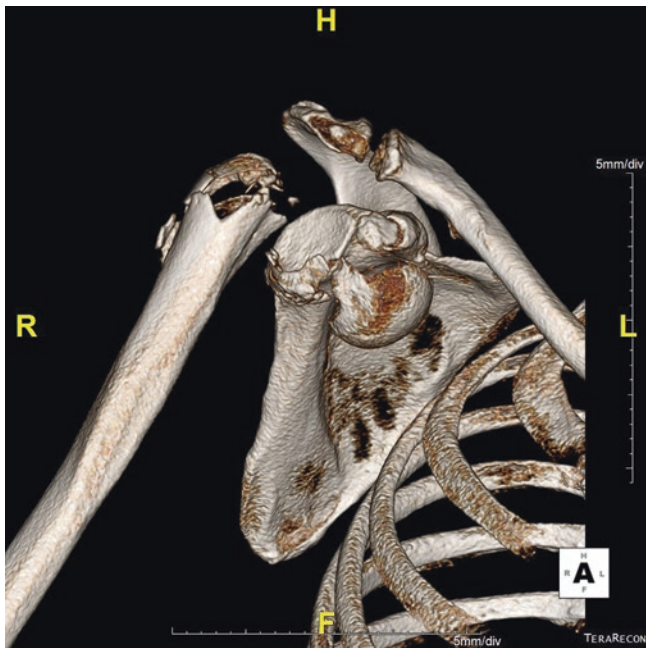


**Fig. 9.126** CT scans demonstrating humeral head fragment anterior to glenoid

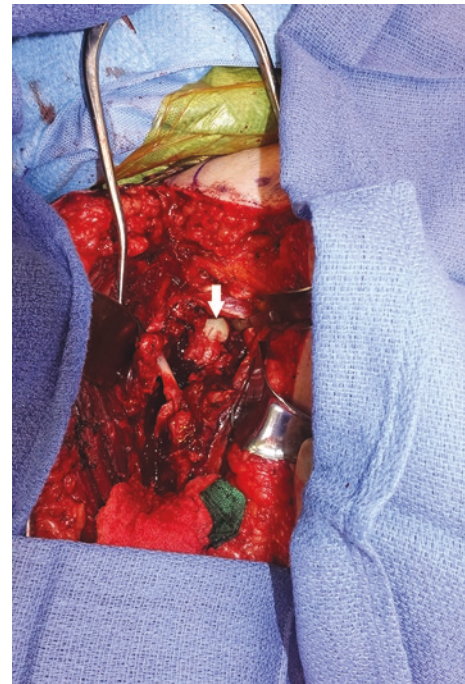


**Fig. 9.127** CT scan demonstrating humeral head fragment anterior to glenoid

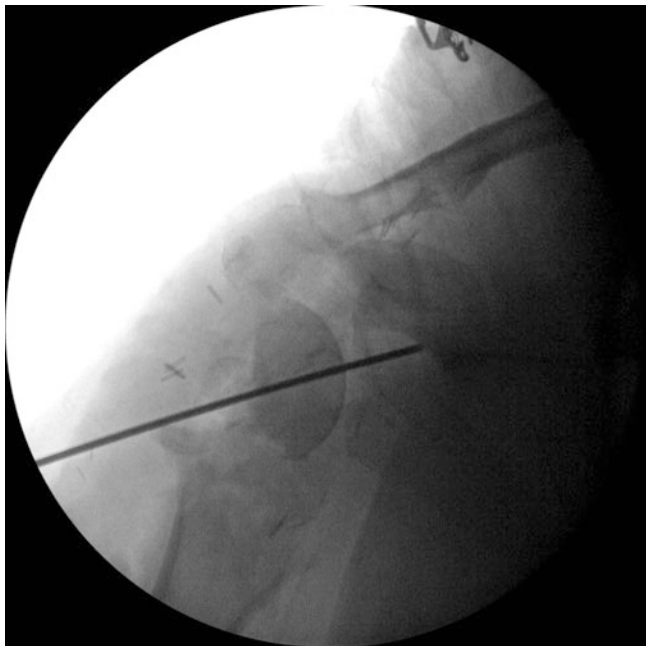




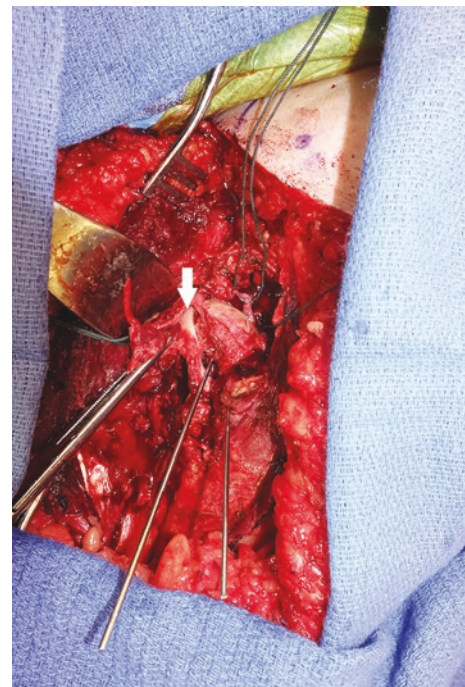
**Fig. 9.128** 3D CT scan showing the anterior displacement of the humeral head and inferior glenoid fracture



**Fig. 9.129** Visualization of the humeral head (*arrow*) with retraction of the conjoint tendon



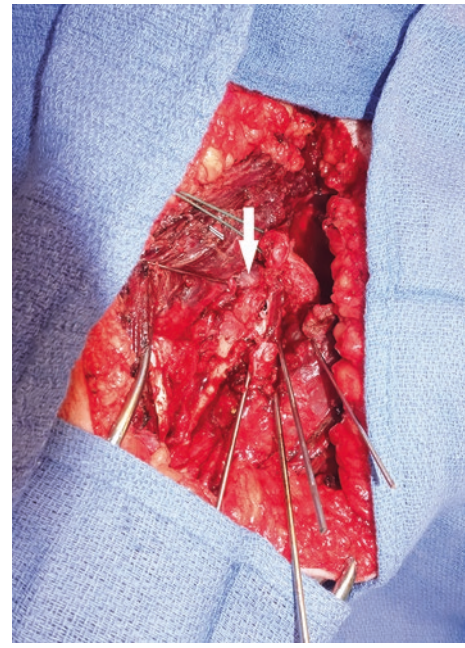
**Fig. 9.130** Humeral head reduced using the Cobb shoehorn technique and stabilized to the glenoid with a K-wire



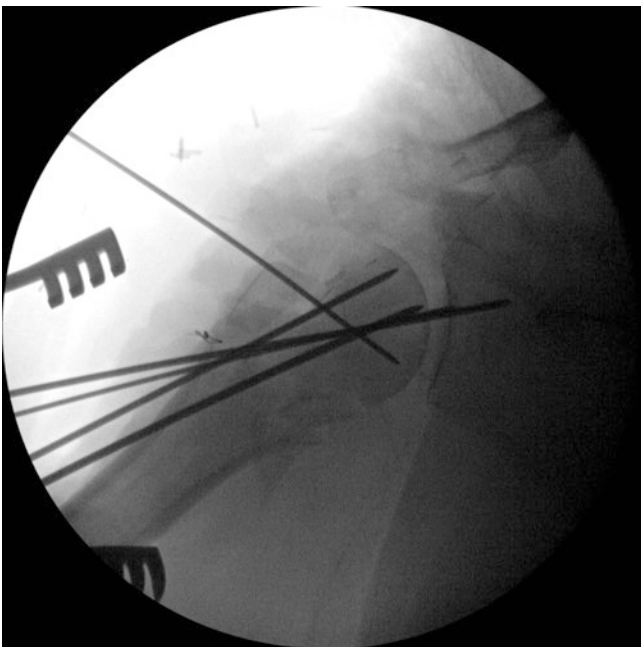
**Fig. 9.131** Shaft and tuberosity fragments reduced to the humeral head. Note the biceps tendon (*arrow*) preserved and resting in longitudinal orientation, reflecting proper fragment alignment and with shaft rotation



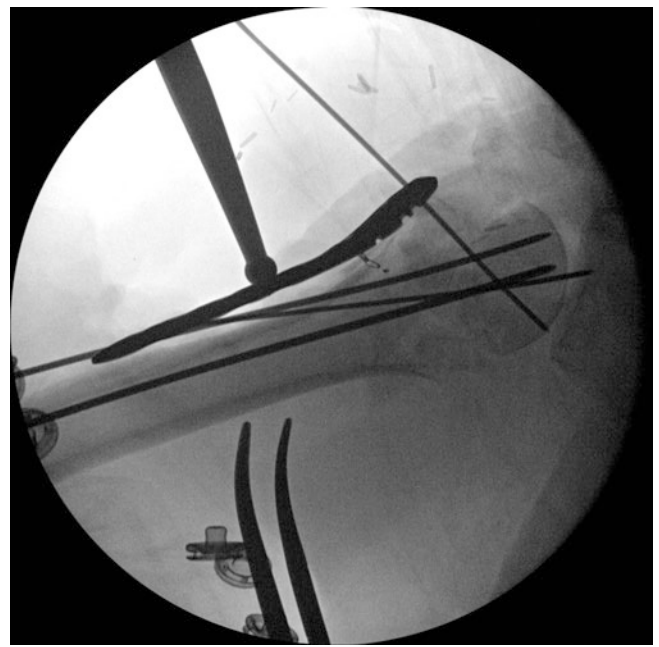
**Fig. 9.132** Radiograph showing fixation



**Fig. 9.133** Sutures placed in subscapularis and fixation of greater tuberosity fragment (*arrow*) with K-wire



**Fig. 9.134** Radiograph of greater tuberosity fragment fixation



**Fig. 9.135** Plate positioning laterally with first screw insertion in shaft to compress bone graft



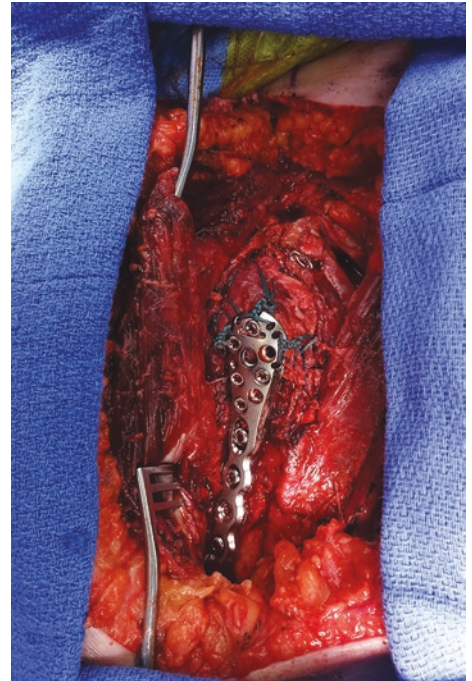


**Fig. 9.136** Y-scapular C-arm radiograph after definitive fixation



**Fig. 9.137** Grashey C-arm radiograph

**Fig. 9.138** Final fixation with rotator cuff sutures tied over the plate







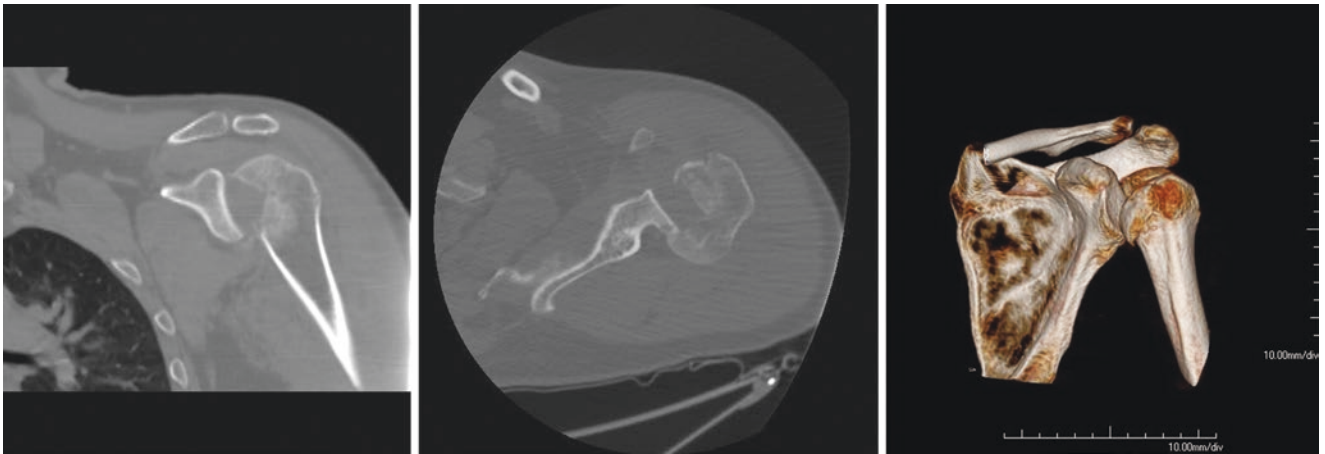
**Fig. 9.139** Postoperative radiographs showing coracoid fracture used to reflect the conjoint tendon reduced and stabilized with interosseous wire, and a 1.5-mm mini-fragment plate used as a three-hole washer

Posterior fracture dislocations are frequently left dislocated until surgical intervention because of the concern over knocking off the head, if not fractured, or displacing a non-displaced humeral head, if fractured. Sometimes with

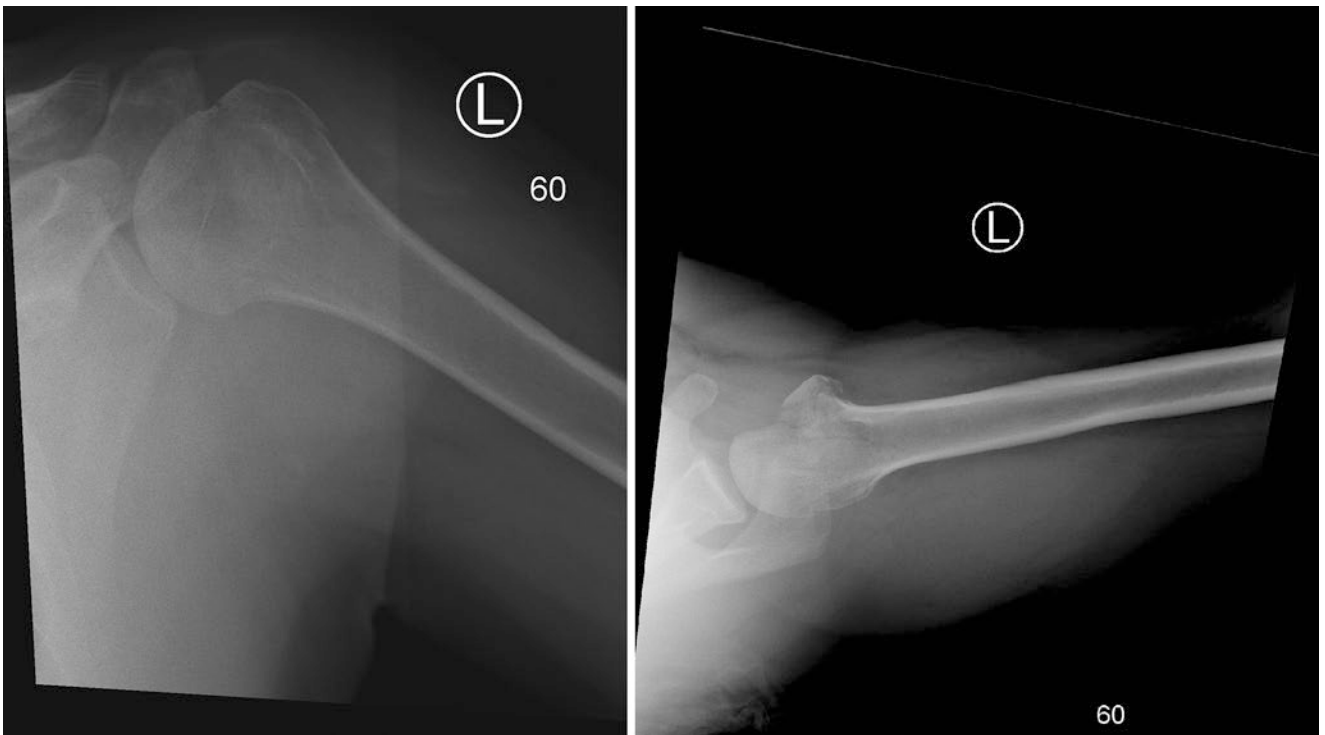
adequate relaxation via either regional or general anaesthesia, you may be fortunate to attain reduction, as illustrated in Figs. 9.140, 9.141, 9.142, 9.143, 9.144, and 9.145.

**Fig. 9.140** Radiograph of left shoulder posterior fracture dislocation in a patient who has just arrived from a referring facility

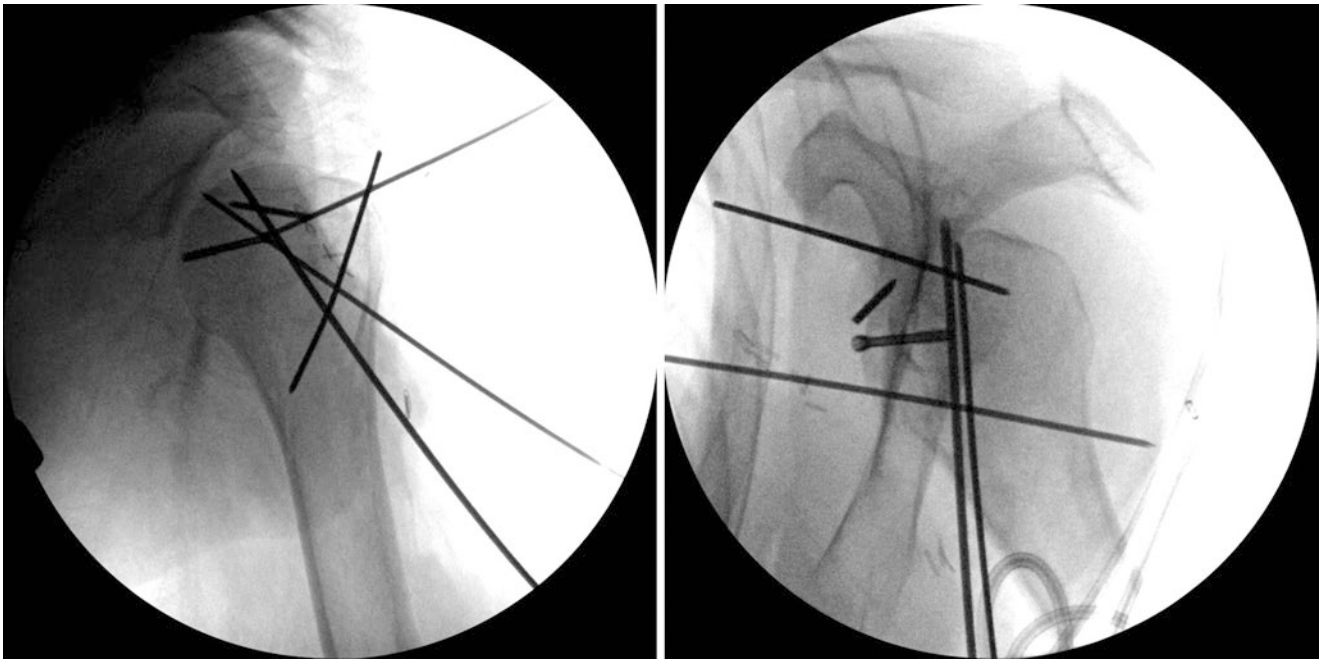




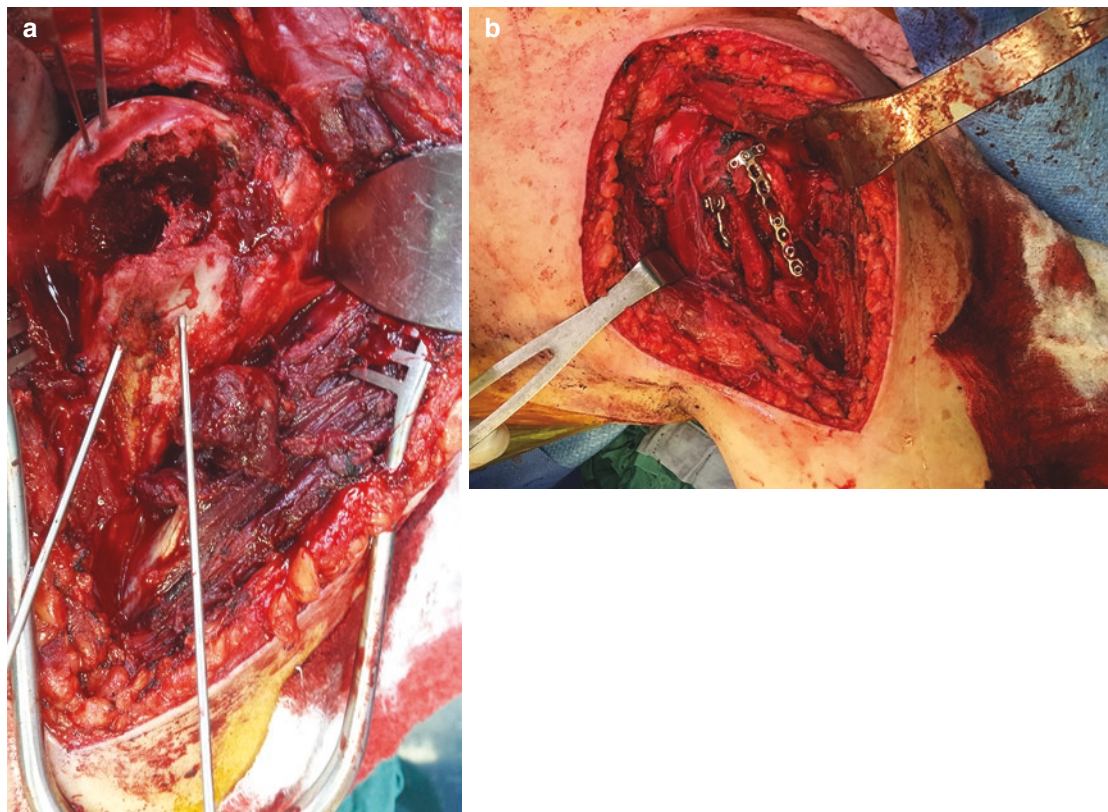
**Fig. 9.141** CT scans demonstrate a head defect and posterior dislocation; a 3D CT scan reveals a lesser tuberosity fracture. The CT scan demonstrates the anatomic neck fracture (same patient as in Fig. 9.76)



**Fig. 9.142** Radiographs following successful closed reduction, revealing large anterior defect with impaction. The patient required intubation for adequate relaxation for reduction of both shoulders to avoid displacement or creation of neck fractures

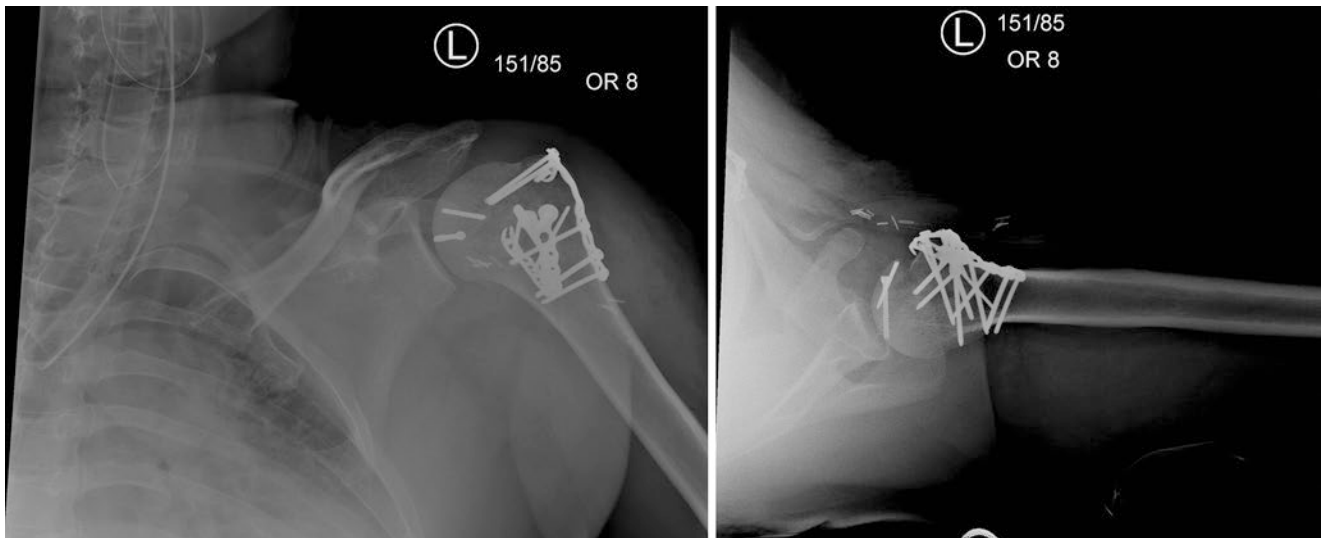


**Fig. 9.143** Provisional fixation



**Fig. 9.144** (a) Large head defect following reduction, requiring bone grafting. (b) Fixation following bone grafting. The plates utilized were mini-fragment locking plates

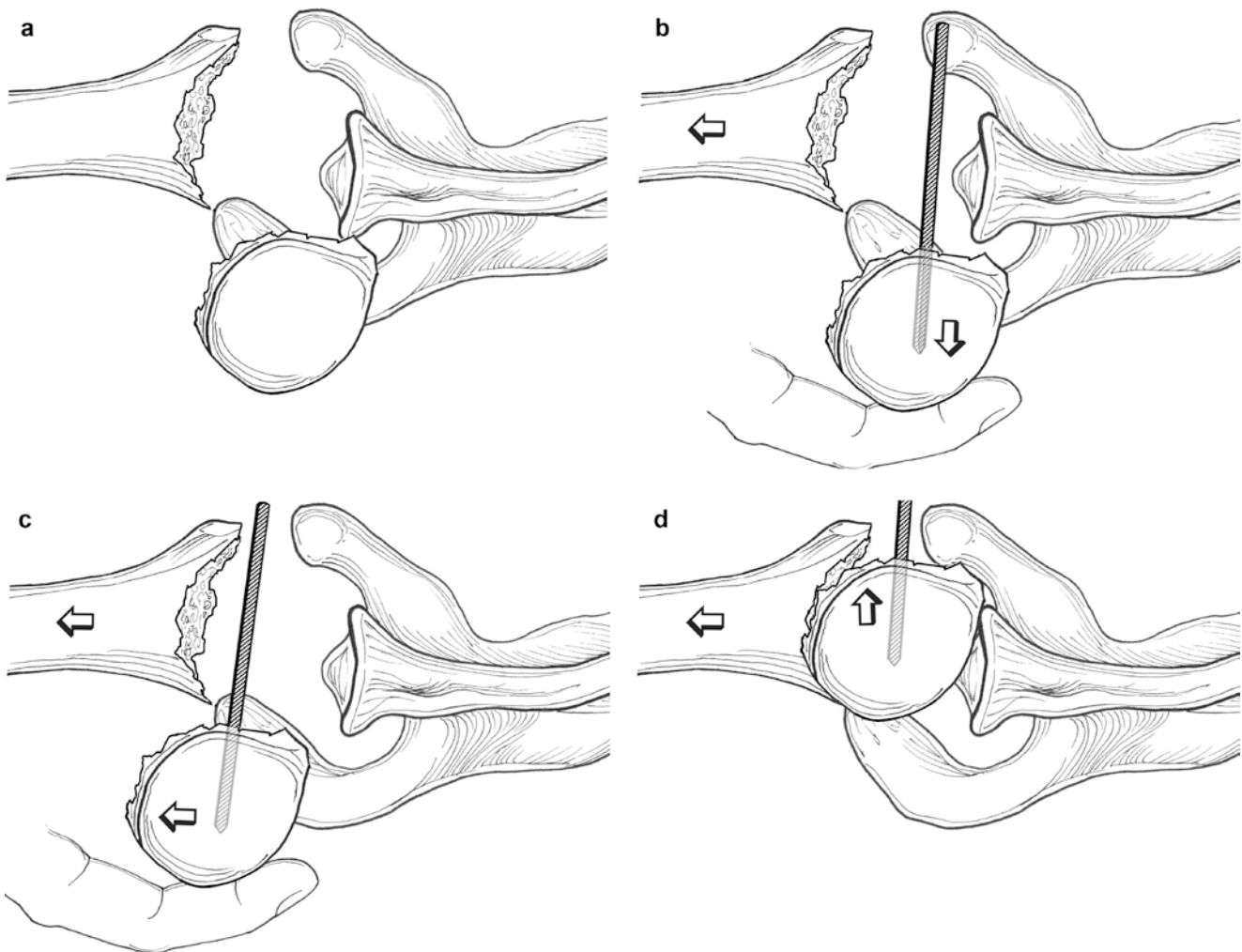




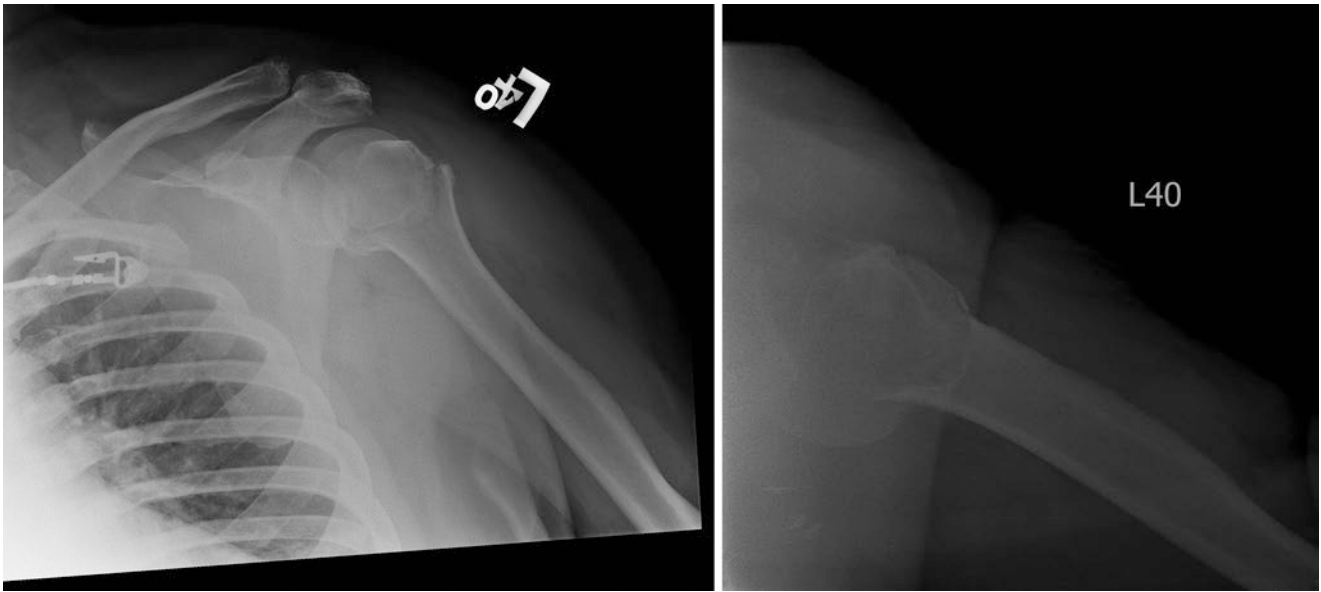
**Fig. 9.145** Postoperative radiographs

Unfortunately, the head is usually locked posterior to the glenoid, which requires reduction and a potential maneuver

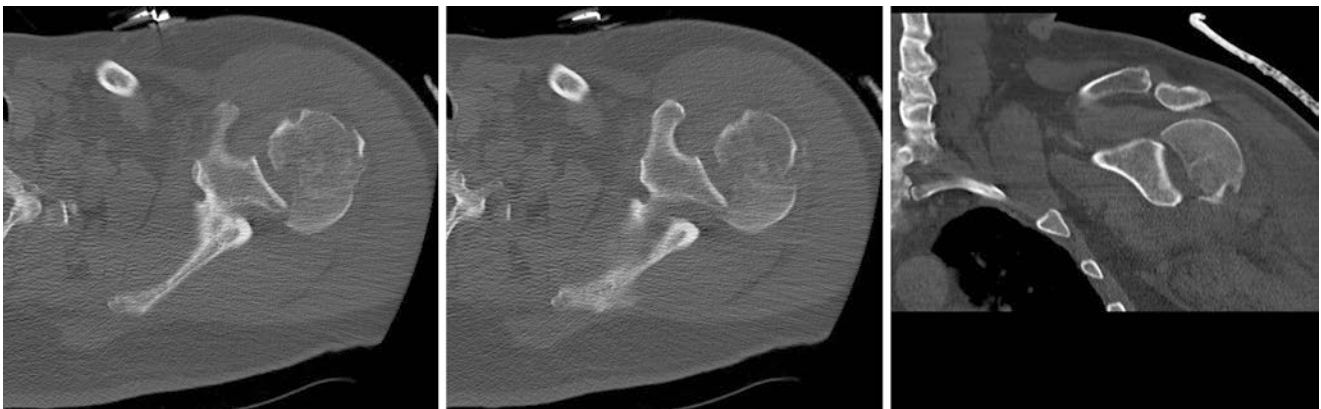
as demonstrated in Figs. 9.146, 9.147, 9.148, 9.149, and 9.150.



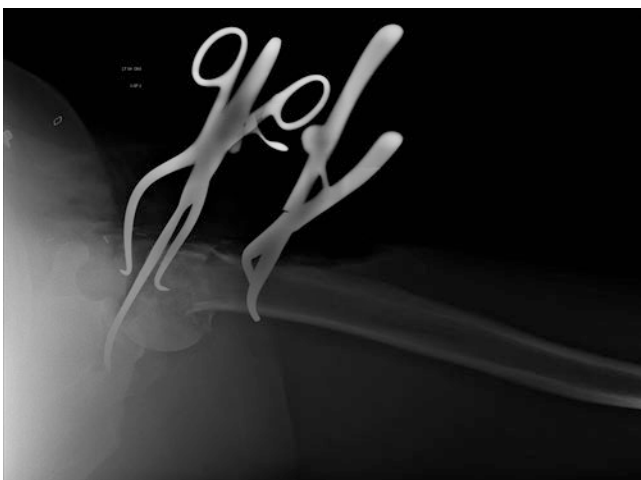
**Fig. 9.146** Steps used to reduce a posterior head dislocation. (a) Insert a large, threaded Steinmann pin. Push posteriorly to disengage; do not pull up first. (b) Lateralize the fragment, then deliver anteriorly. (c, d) denote sequence of reduction



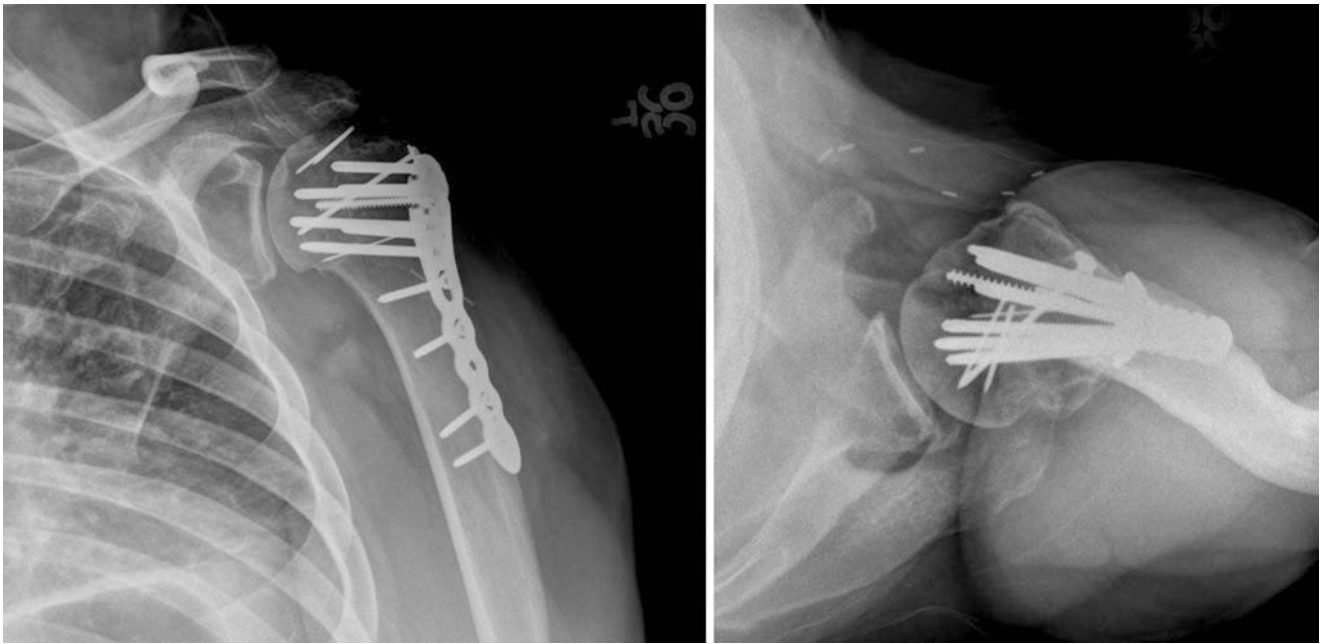
**Fig. 9.147** Injury radiographs of a left posterior fracture dislocation



**Fig. 9.148** CT scan revealing the locked posterior head fragment



**Fig. 9.149** Intraoperative axillary radiograph prior to insertion of threaded Steinmann pin, showing the use of a Gelpi retractor to gain access and adequate distraction to deliver the head fragment



**Fig. 9.150** Final fixation following the ORIF

Once the fixation is completed, a range-of-motion program is undertaken in two radiographic planes, using the Grashey view, in a 90° live sweep to evaluate for screw length, and then a rotating Y-scapular sweep. I feel this step is important, to prevent missing any screw penetration and allowing screw readjustment as indicated. Screw penetration has been reported in nearly 15% of cases in one report [36]. I also inspect the proximal humeral shaft, neck, head, and lateral border of the scapula for reestablishment of Shenton's line (which has been dubbed the *Gothic arch sign*). Jet lavage is then performed. Sutures are tied and a final check performed under image. The deltopectoral interval is closed with a running 2-0 Vicryl or 2-0 PDS suture. Fracture dislocations will have specific reduction maneuvers predicated upon the direction of dislocation, such as temporary fixation of the humeral head to the glenoid and building around the head.

#### 9.2.4 Patient Rehabilitation

The postoperative therapy program begins with supported Codman's exercises for 2 weeks, followed by passive range of motion for 2 weeks, then active motion for 2 weeks. Discontinuation of the sling and strengthening can begin at 8 weeks, with full weight-bearing at 3 months.

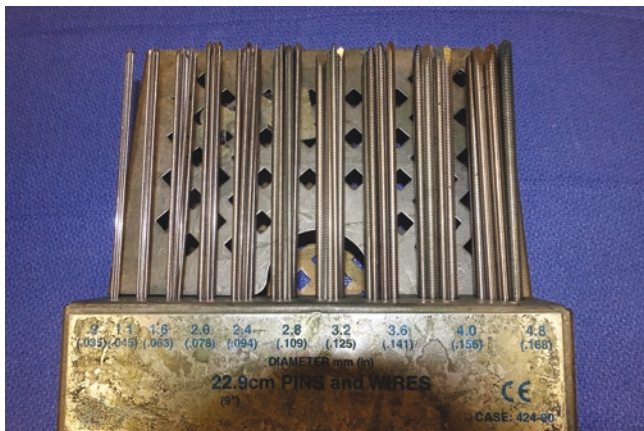
### 9.3 Other Techniques

#### 9.3.1 Intramedullary nailing

Three other techniques to be demonstrated are the intramedullary (IM) nail, percutaneous screws, and percutaneous K-wires. IM nailing of proximal humeral fractures is usually performed for surgical neck fractures, but can be done with fractures associated with greater tuberosity fractures that are nondisplaced or minimally displaced. These patterns also are very amenable to ORIF, using locking plates, and they achieve similar outcomes.

Two important aspects of IM nailing are the starting point and the proximal fragment manipulation. Both are facilitated with the use of a large-thread Steinmann pin placed percutaneously into the greater tuberosity and humeral head (Figs. 9.151, 9.152, and 9.153).



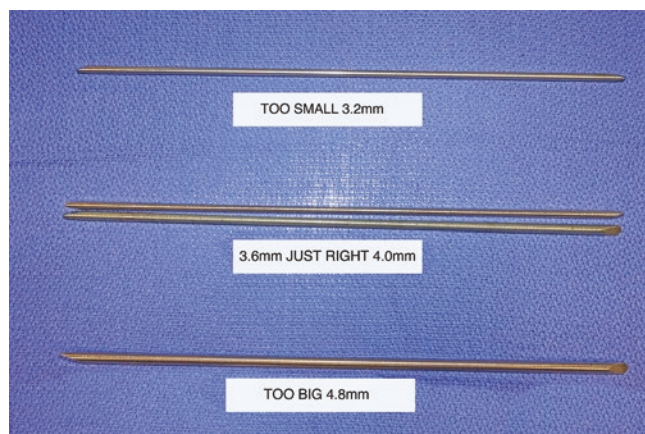


**Fig. 9.151** Threaded K-wires and Steinmann pins



**Fig. 9.152** Size options

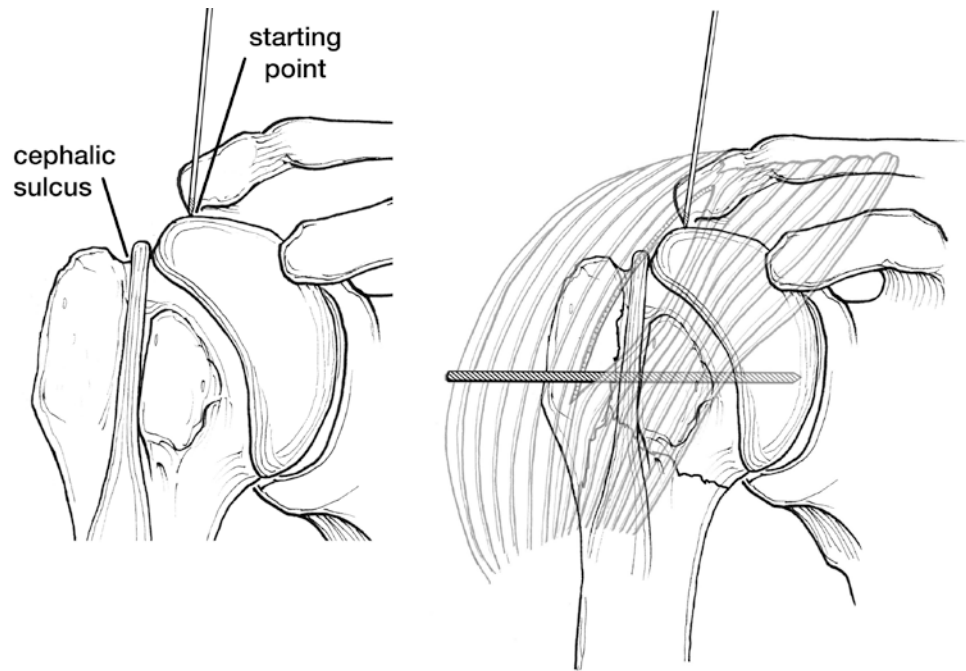
**Fig. 9.153** Sizes of Steinmann pins used as reduction devices in the humeral head



The pin prevents migration or displacement of a greater tuberosity fracture, if present, and also functions as a joystick, preventing the head from following the shaft during traction and bringing the head into a valgus adducted position. The valgus adducted position allows access to the starting point. I prefer the starting point to be medial to the cephalic sulcus. The medial position assists in preventing a varus malalignment and decreases the possibility that the guide wire or the cannulated over-reamer will fall into the greater tuberosity fracture, when such a fracture is present.

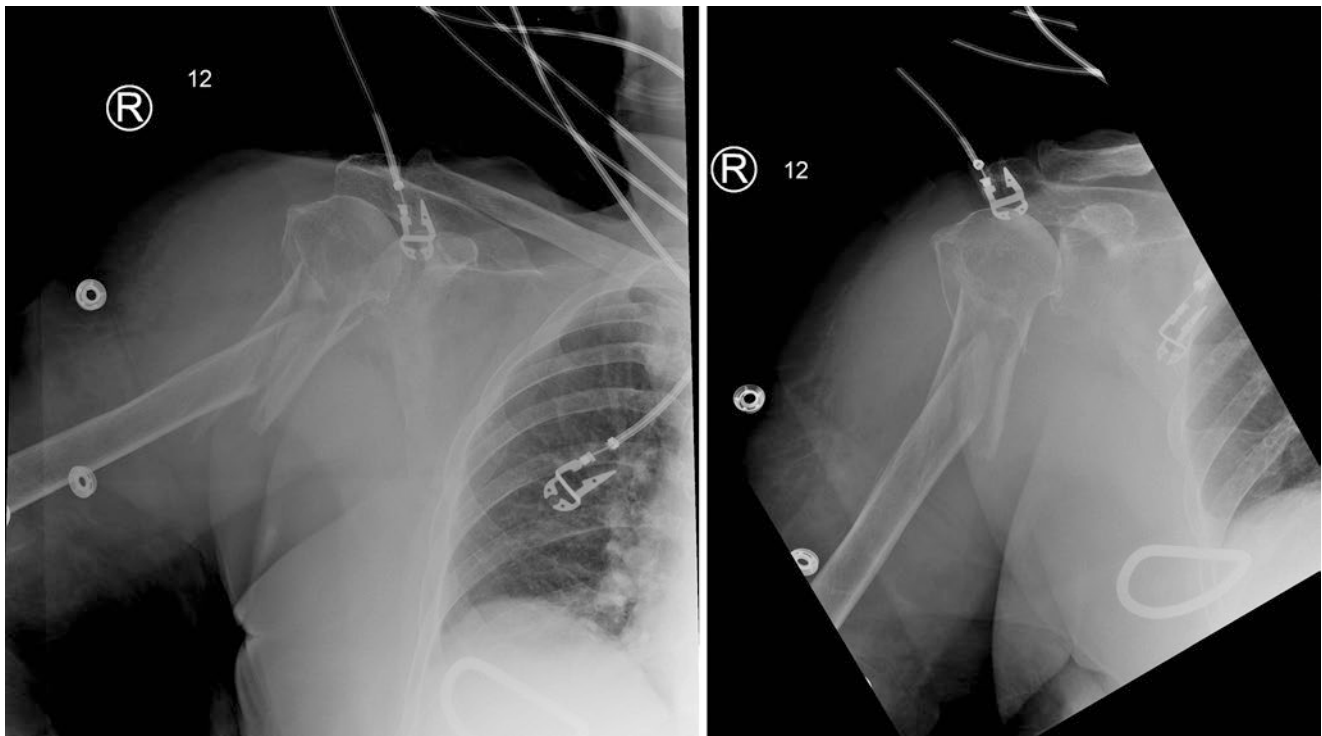
Regardless of the device to be inserted, I utilize a skin incision anterolateral to the acromion. The deltoid is split in the proposed interval between the anterior and middle heads. Some of the deltoid may need to be elevated off the acromion, and sometimes a small portion of the acromion needs to be nibbled out to get the guide wire medial and superior. When the guide wire is positioned, an incision is made in the cuff, and the cuff is retracted to allow the starting reamer insertion (Fig. 9.154).

**Fig. 9.154** Diagrams of starting point for intramedullary fixation of the proximal humeral or humeral shaft fracture

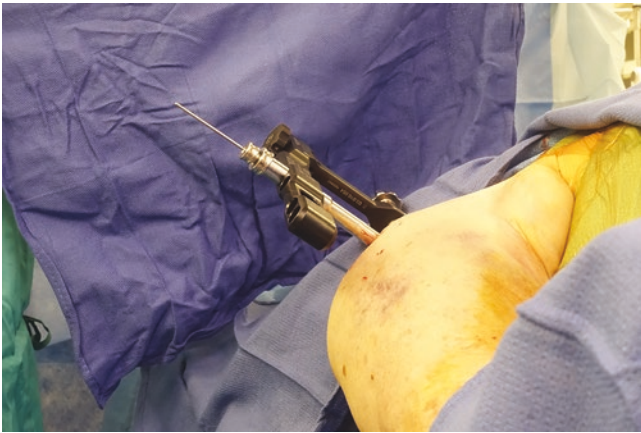


I use either a locking IM device like the Stryker Nail® or the Synthes proximal humerus nail (PHN) with spiral blade. With the spiral blade system, the jig needs to be almost 45° internally rotated relative to the floor to account for head

retroversion and bumping up of the shoulder (Figs. 9.155, 9.156, 9.157, 9.158, 9.159, 9.160, 9.161, 9.162, 9.163, 9.164, 9.165, 9.166, 9.167, 9.168, 9.169, and 9.170).



**Fig. 9.155** Radiographs of right proximal humeral fracture with neck and shaft fractured



**Fig. 9.156** Jig in alignment for blade insertion. Note the amount of internal rotation required to account for the patient positioning and retroversion. The jig is almost 45° internally rotated to the floor

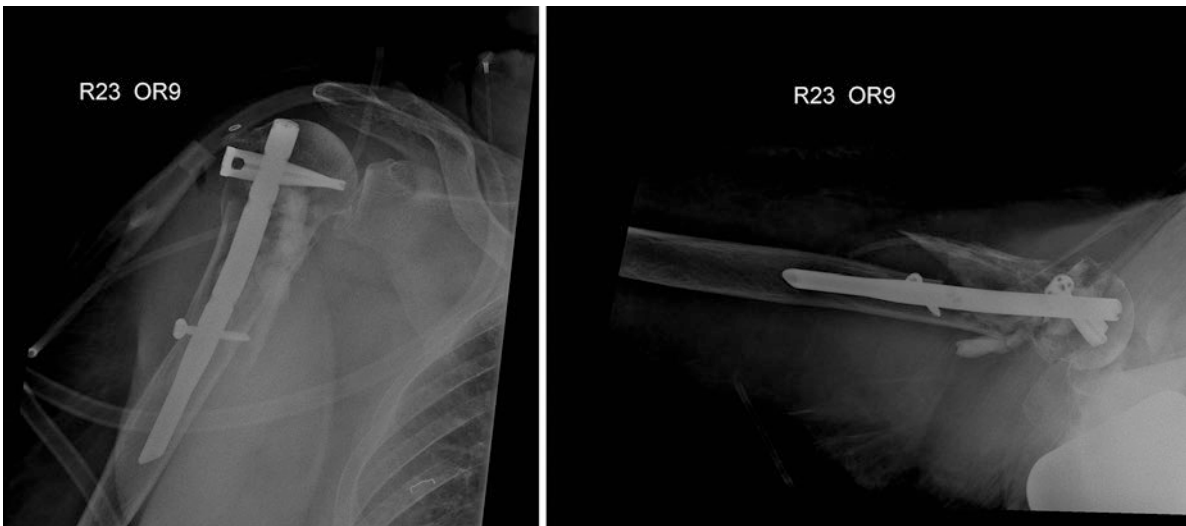


**Fig. 9.157** Jig positioned for blade insertion



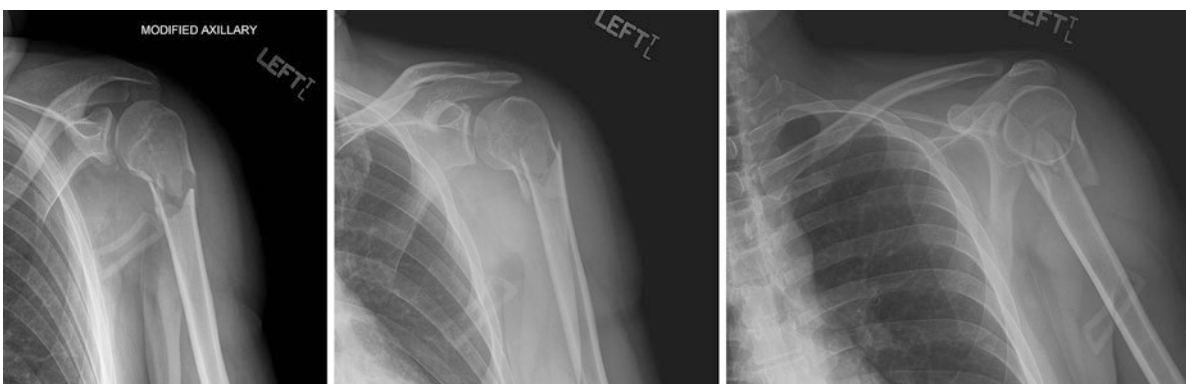
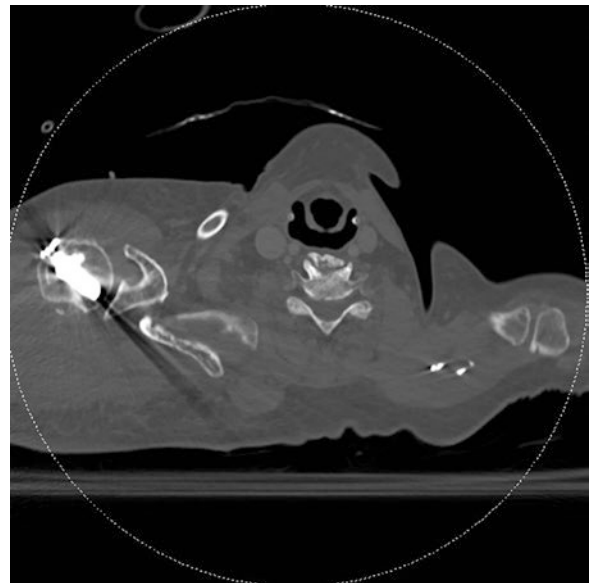
**Fig. 9.158** Intraoperative C-arm radiographs with blade insertion





**Fig. 9.159** Postoperative radiographs. Note attempt at bone substitute injection to improve blade purchase

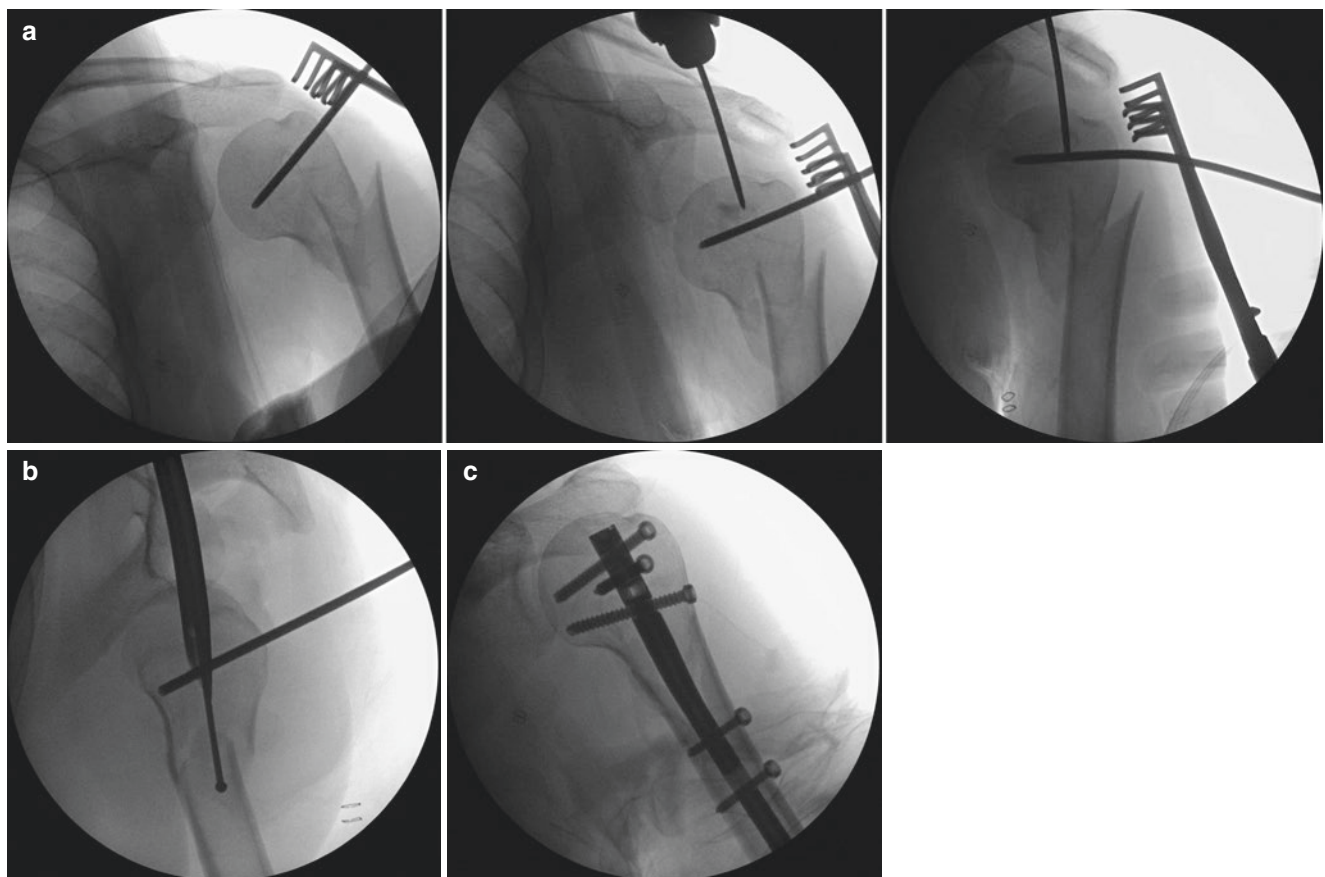
**Fig. 9.160** Incidental finding on CT angiography (CTA) of the proper position of the blade pointing to the glenoid, reaffirming the degree of internal rotation of the jig needed during insertion



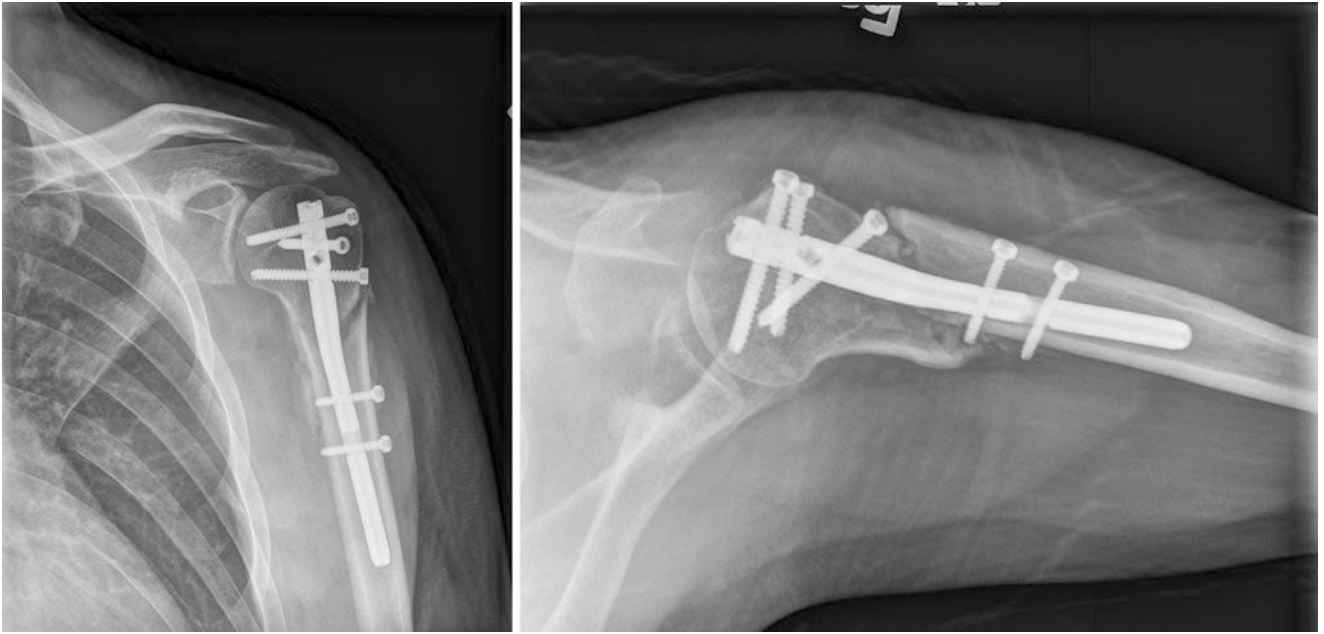
**Fig. 9.161** Radiographs of left proximal humeral shaft neck fracture with plans for intramedullary fixation to allow the patient to return to work without a sling or brace



**Fig. 9.162** 3D CT scan demonstrating displacement



**Fig. 9.163** Intraoperative C-arm radiographs. (a) A threaded Steinmann pin is used as a joystick, then the starting point, followed by reduction of the fracture. Note the “English” on the Steinmann pin resisting the traction. (b) Y-scapular view of guide wire passage. (c) Intraoperative Grashey view

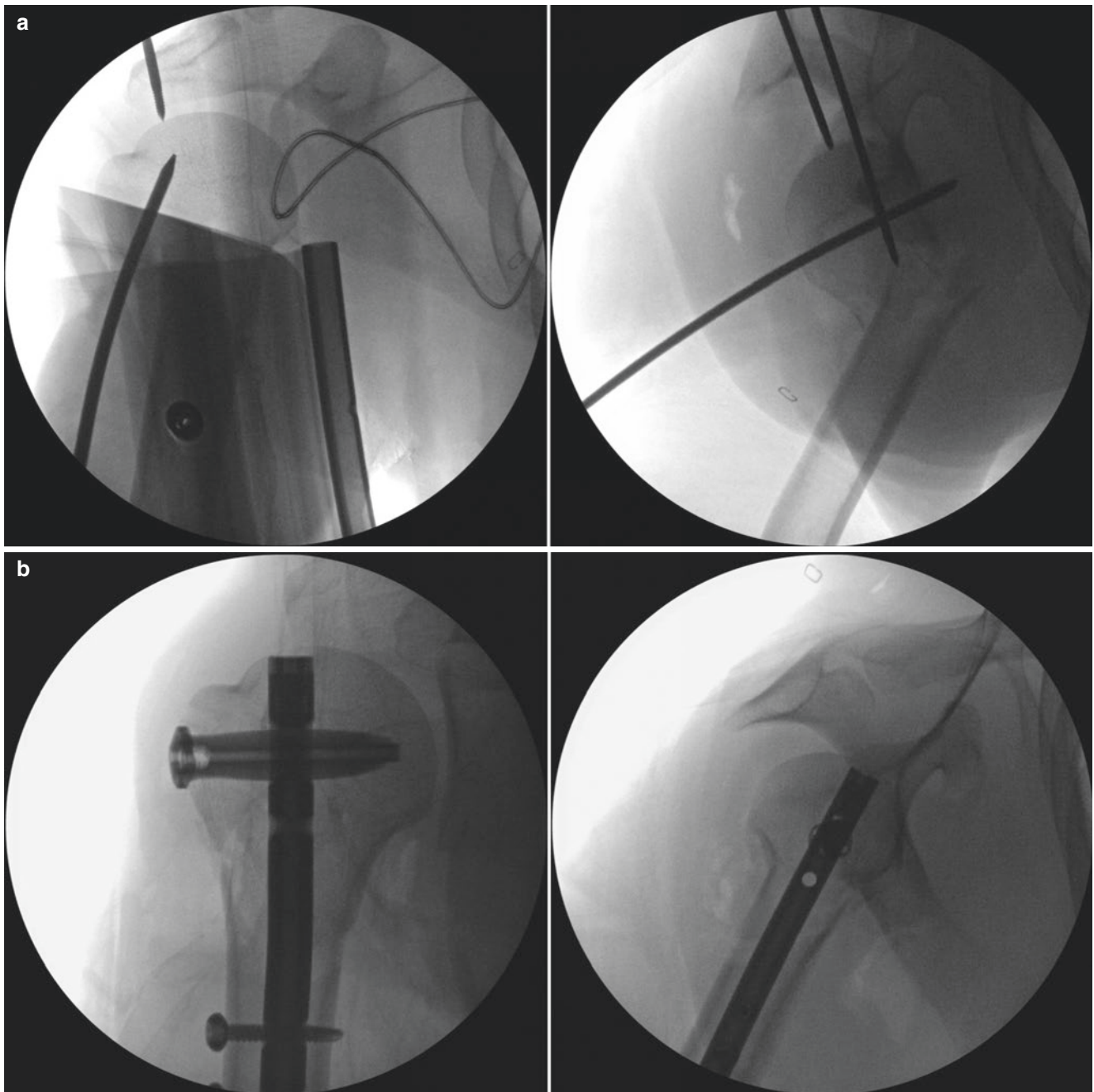


**Fig. 9.164** Follow-up radiographs with callus present

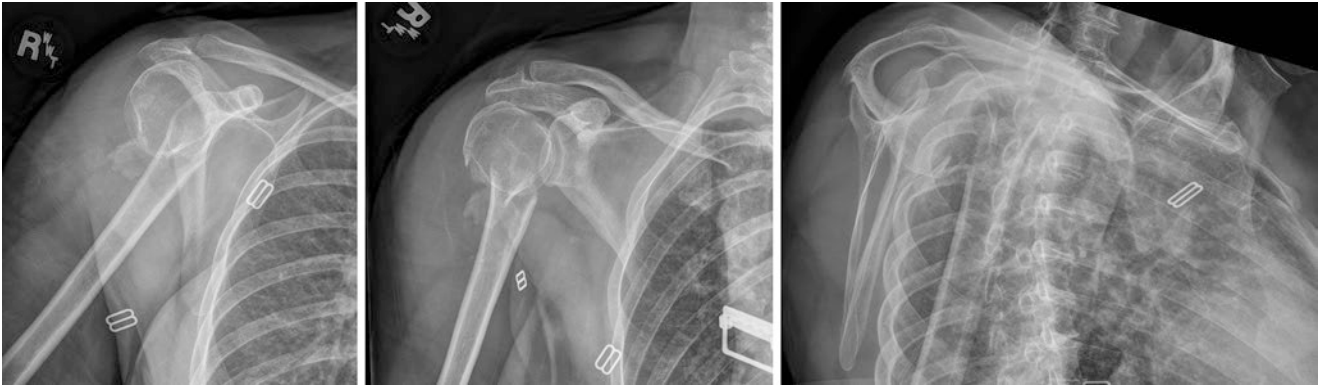


**Fig. 9.165** Radiographs of right proximal humeral fracture





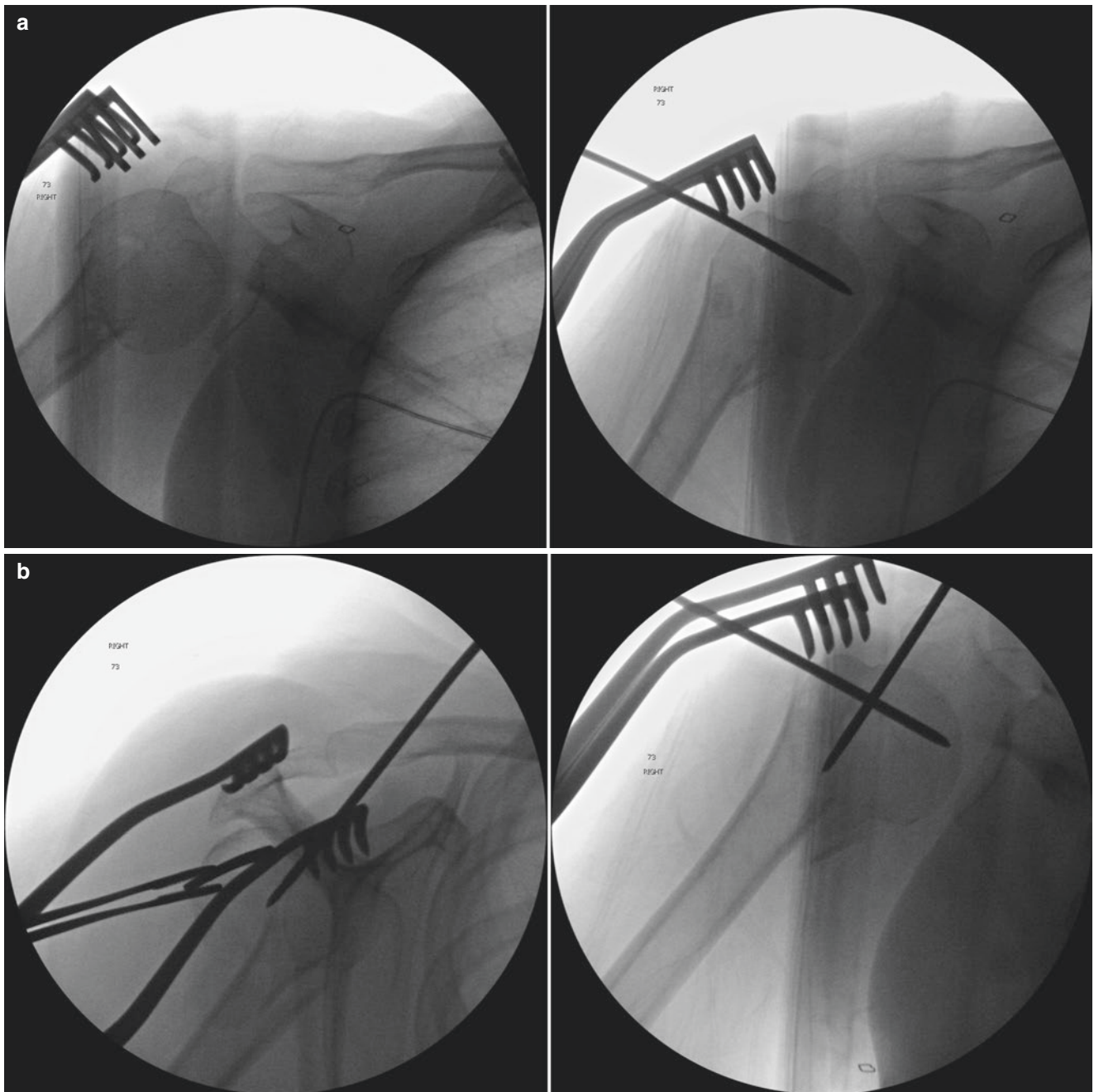
**Fig. 9.166** (a) Starting point acquisition. The initial guide was too posterior; it was left in place and a new guide wire (*arrow*) was positioned. Note joystick for head control. (b) Final intraoperative C-arm radiographs



**Fig. 9.167** Radiographs of right proximal humeral fracture

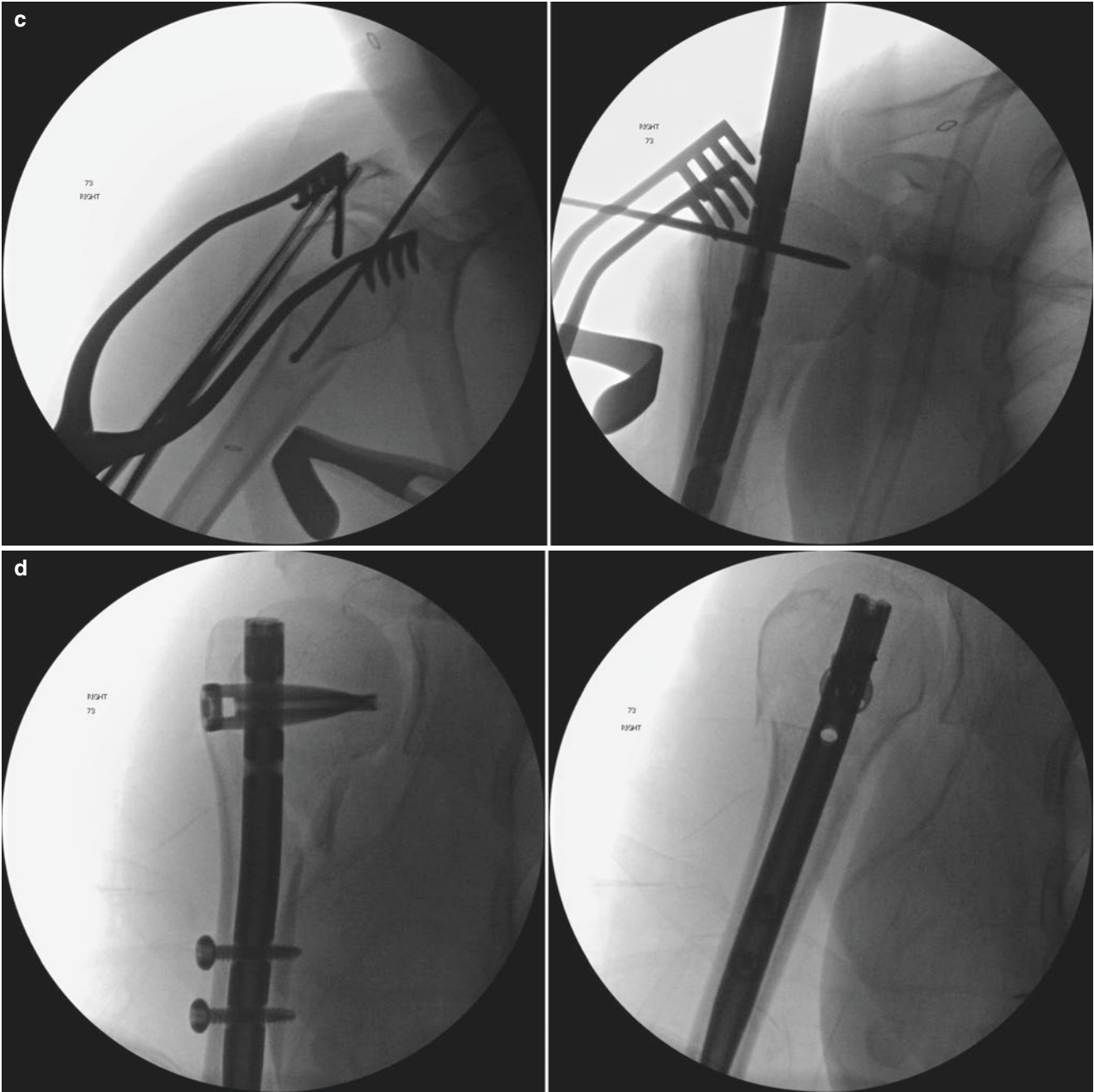


**Fig. 9.168** CT scan demonstrating a nondisplaced fracture of the greater tuberosity, which can be stabilized with a threaded Steinmann pin; the medial starting point allows intramedullary fixation

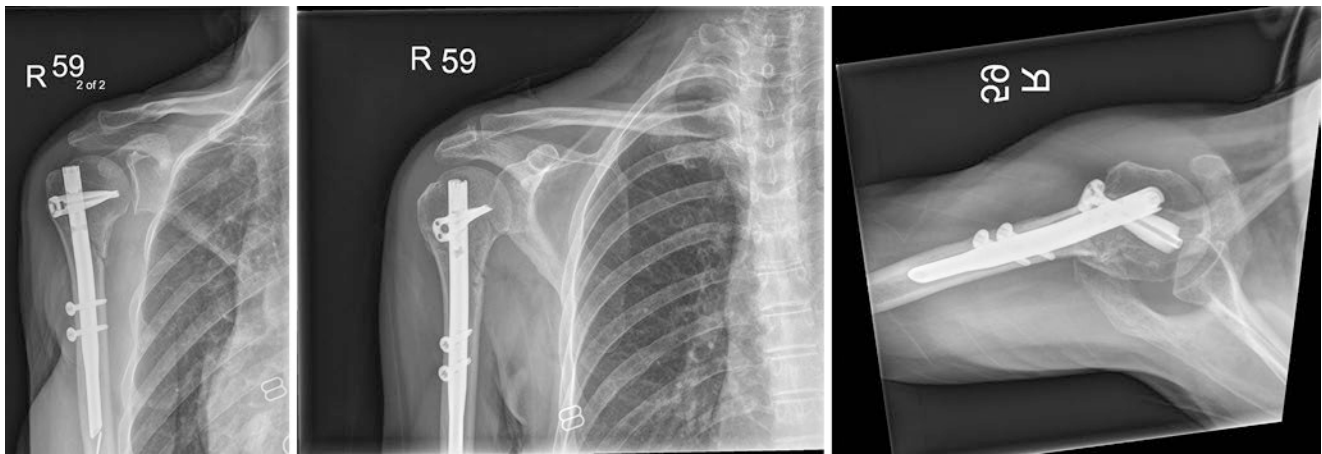


**Fig. 9.169** (a) Insertion of threaded Steinmann pin. (b) Starting point and guide wire insertion. (c) Kocher clamp holding Steinmann pin to keep hands out of the field. (d) Spiral blade inserted





**Fig. 9.169** (continued)



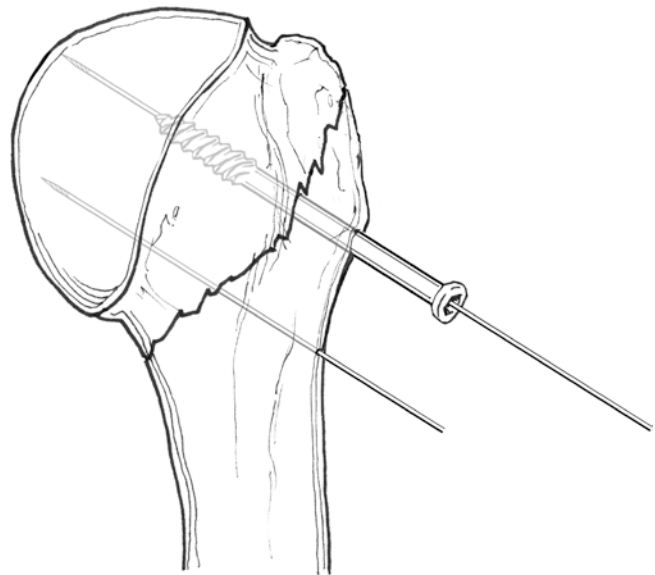
**Fig. 9.170** Follow-up radiographs. With the degree of displacement in the three previous cases, nonoperative treatment was not optimal, and plate fixation could also be selected

### 9.3.2 Percutaneous Screws

Percutaneous screws are most frequently used in neck fractures with a specific fracture pattern of obliquity—low-medial to high-lateral—and patients are usually under

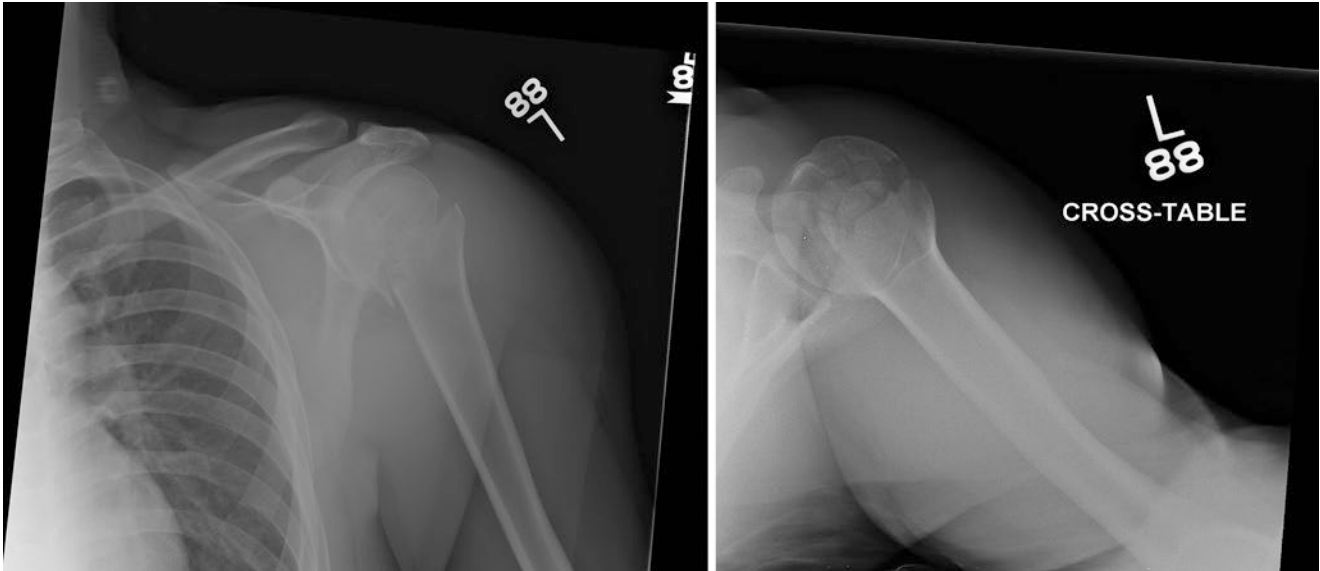
the age of 45, with good bone quality. The obliquity of the fracture, providing a more perpendicular orientation to the lateral cortex, facilitates screw insertion and minimizes the walking of the guide wires during positioning (Fig. 9.171).

**Fig. 9.171** Guide wire and screw insertion sequence for percutaneous screw fixation. Note the intact lateral cortex to support the screws



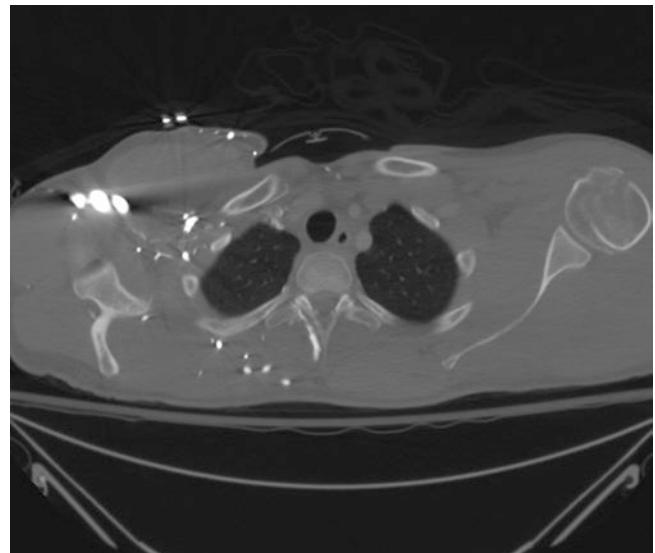
A threaded Steinmann pin facilitates control and manipulation of the humeral head. Reducibility is performed and confirmed under C-arm control. I generally use 7.3-mm cannulated screws, but in smaller humeri I have used 4.5-mm cannulated screws.

Two guide wires are placed, measured, and overdrilled. Screw insertion follows, with the more superior screw being placed first to correct any varus angulation (Figs. 9.172, 9.173, 9.174, 9.175, 9.176, and 9.177).

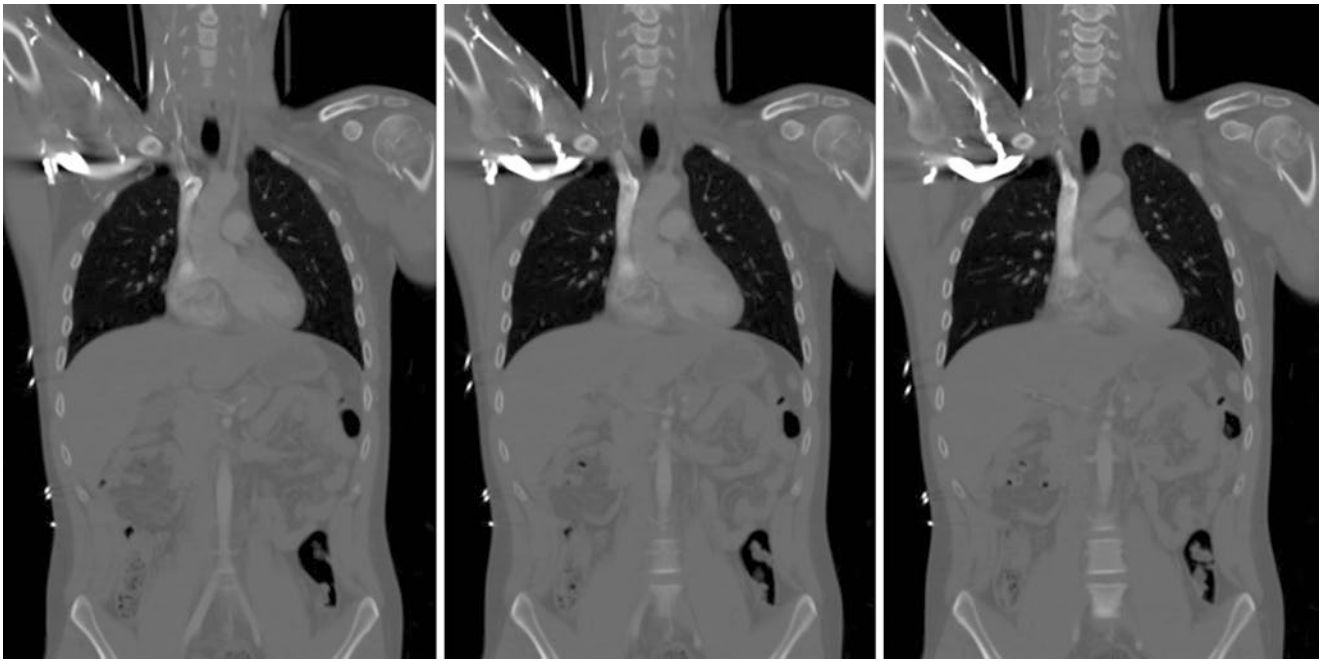


**Fig. 9.172** Radiographs of left proximal humeral fracture with proximal lateral cortex

**Fig. 9.173** Axial CT scan of left proximal humeral fracture



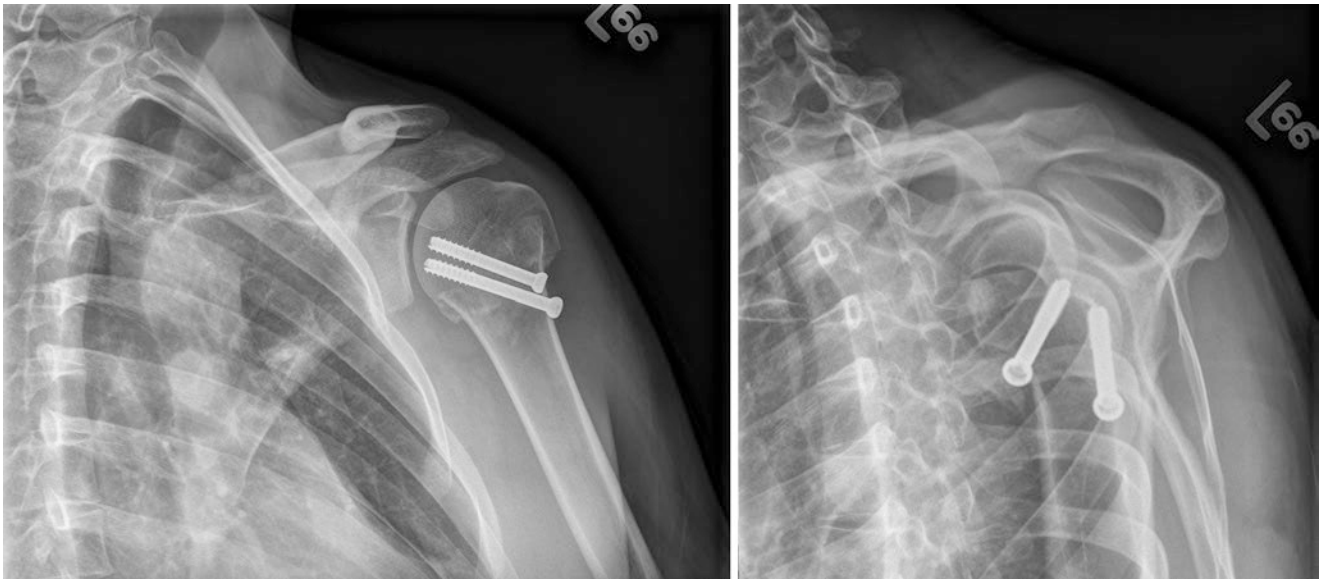




**Fig. 9.174** Non-shoulder-dedicated coronal CT scan with left proximal humeral fracture pattern amenable to percutaneous screw fixation



**Fig. 9.175** Intraoperative C-arm radiographs following insertion of a percutaneous cannulated 7.3-mm screw, with some impaction and medialization noted



**Fig. 9.176** Radiographs at time of discharge, with no complaints and full range of motion



**Fig. 9.177** Radiographs at time of discharge. The lateral screw head appears proud, which is common because counter-sinking is not performed. A washer could be used, but I have not found this to be needed

Patient rehabilitation begins with supported Codman exercises for about 2 weeks, then full range-of-motion exercises, but patients are restricted from weight-bearing activities for 3 months.

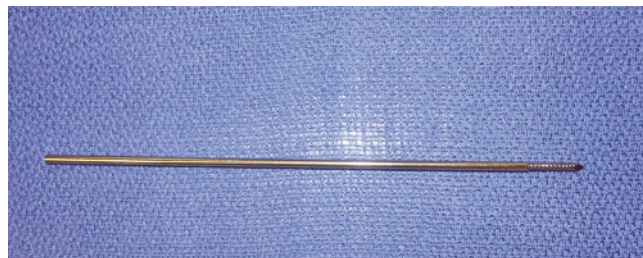
### 9.3.3 Percutaneous K-wire fixation

Percutaneous K-wire fixation may be performed for almost any fracture pattern amenable to closed reduction. This excludes

irreducible fracture dislocations. Extenuating circumstances requiring minimum blood loss and minimum operating room time may necessitate this percutaneous approach rather than ORIF.

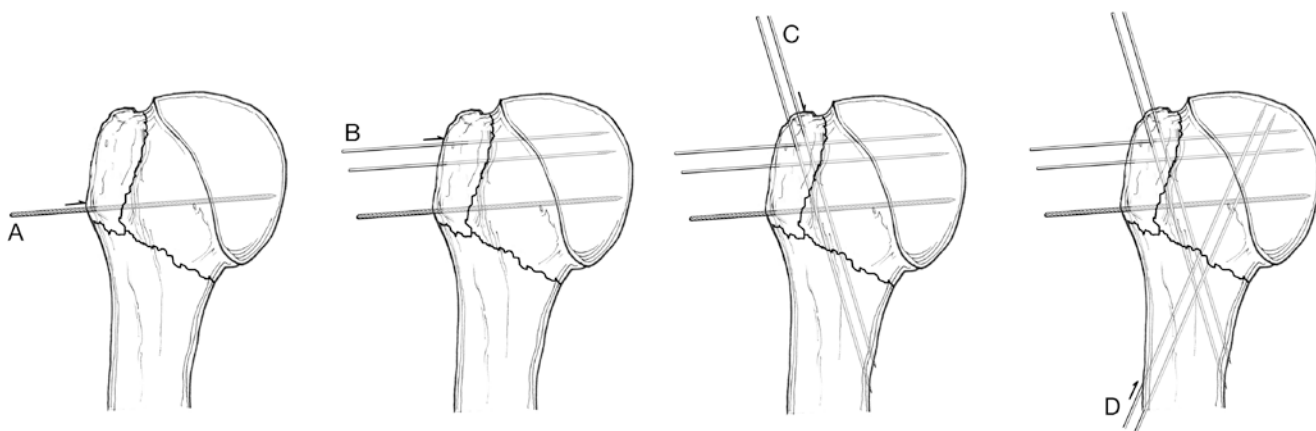
Fixation is performed using 2.5-mm threaded-tip K-wires from the Synthes Small External Fixator® set (Fig. 9.178).

**Fig. 9.178** Threaded-tip 2.5-mm pin from the Synthes Small External Fixator® set



Smooth K-wires tend to migrate, and fully threaded K-wires have a tendency to displace fracture fragments during insertion, but threaded-tip wires address both issues. I

generally use six wires (Fig. 9.179). (I must give due credit to Dr. Steve Benirschke for passing along that pearl.)



**Fig. 9.179** Sequence of pin placement in percutaneous fixation of a proximal humeral fracture

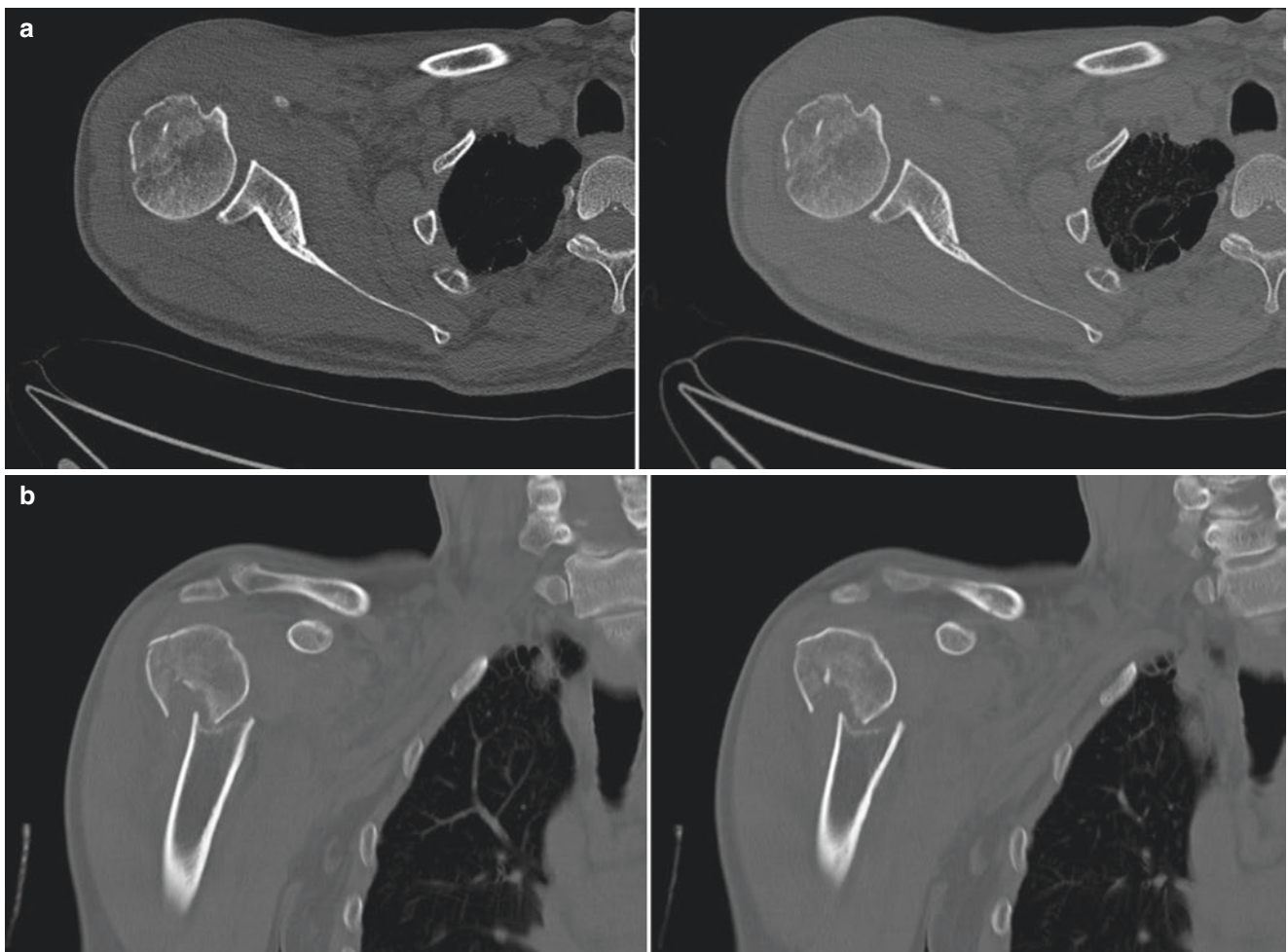
Regardless of the sequence of insertion, I use the threaded Steinmann pin first, placed in the greater tuberosity and advanced into the humeral head. The sequence of K-wire fixation is either two wires transversely in the greater tuberosity and humeral head or two from the tuberosity into the medial neck. The last two are from the shaft, aimed proximal into the head; these can be difficult to insert because of the obliquity of insertion. A soft-tissue protector helps in preventing proximal K-wire walking when you drop your hand

to get the shot into the head. One K-wire should be placed very anteriorly, in a more anterior position than you might think. The wires are cut just beneath the skin with a bolt cutter, and I use a dental pick in the puncture hole, then lift to get the fascia and the subcutaneous tissue over the end of the cut wire (Figs. 9.180, 9.181, 9.182, 9.183, 9.184, 9.185, 9.186, 9.187, 9.188, 9.189, 9.190, 9.191, 9.192, 9.193, 9.194, 9.195, 9.196, and 9.197).



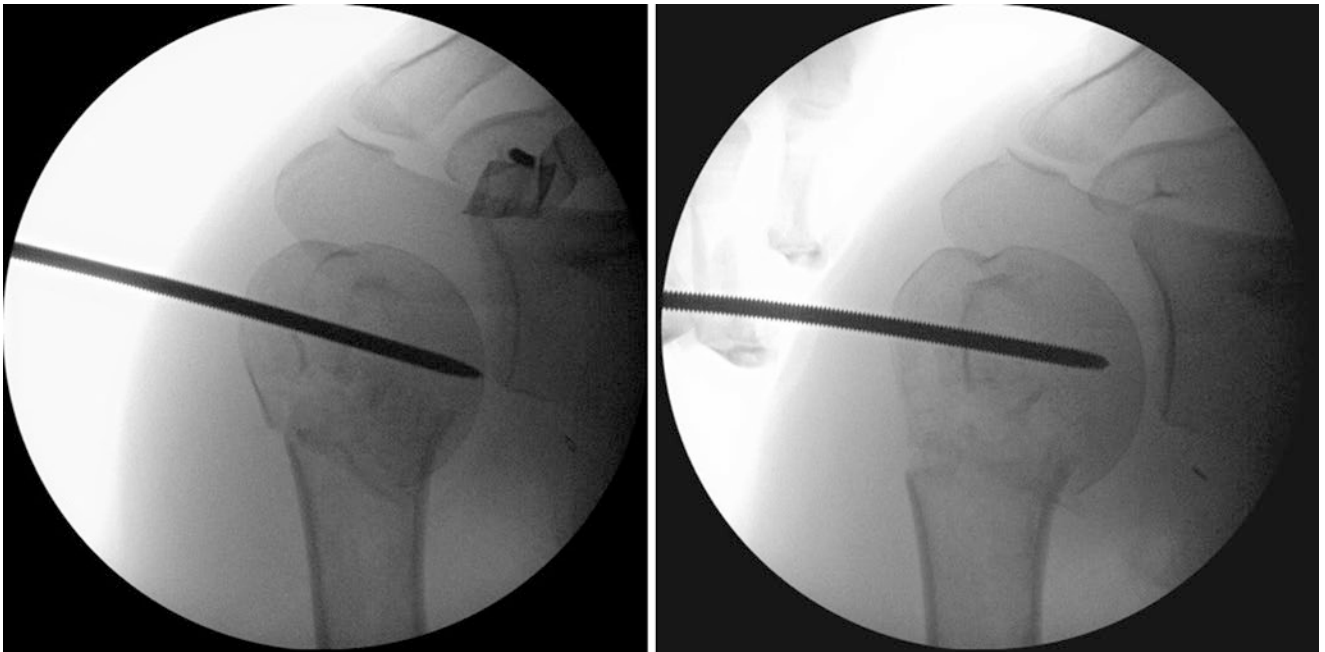


**Fig. 9.180** Injury radiographs of right proximal humeral fracture

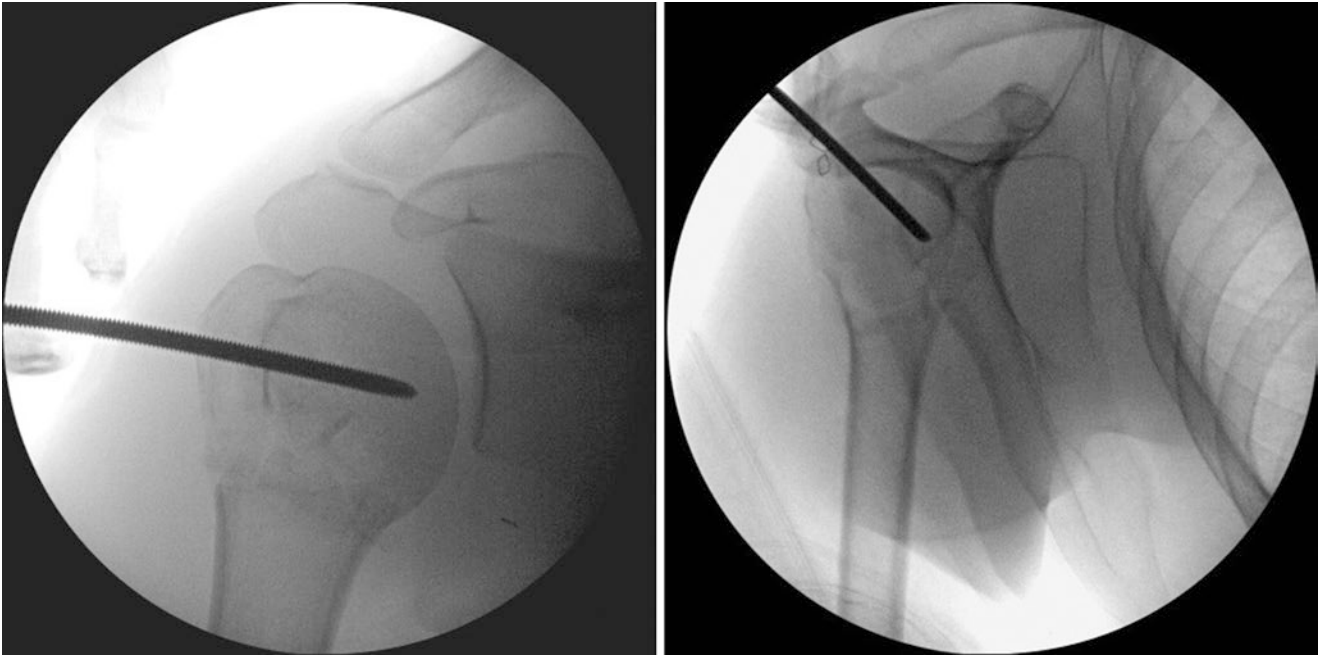


**Fig. 9.181** (a) CT scan demonstrating comminution without displacement of the head fragments. There was concern over nailing, and plate fixation was also an option; percutaneous fixation was selected. (b) Coronal CT scan

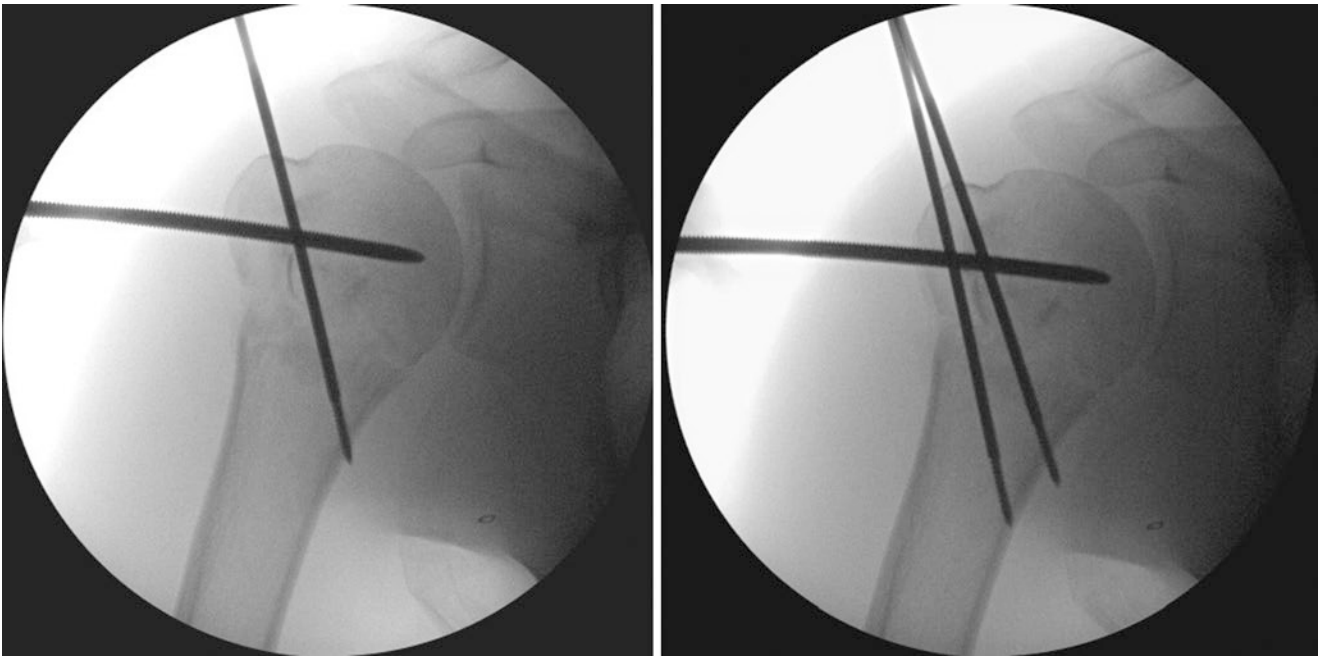
**Fig. 9.182** Intraoperative axillary radiograph to confirm reduction of the shaft to the head



**Fig. 9.183** Sequence of percutaneous fixation with Steinmann pin insertion and cephalic sulcus rotation and view acquired

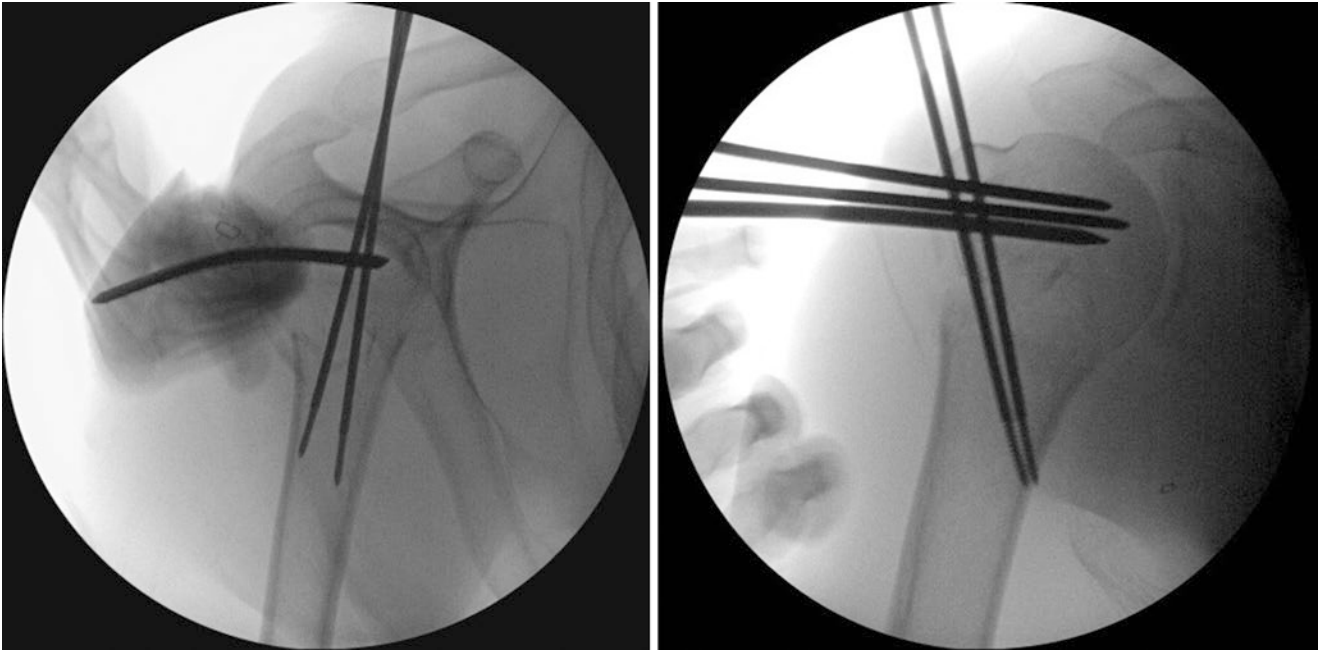


**Fig. 9.184** Reduction obtained

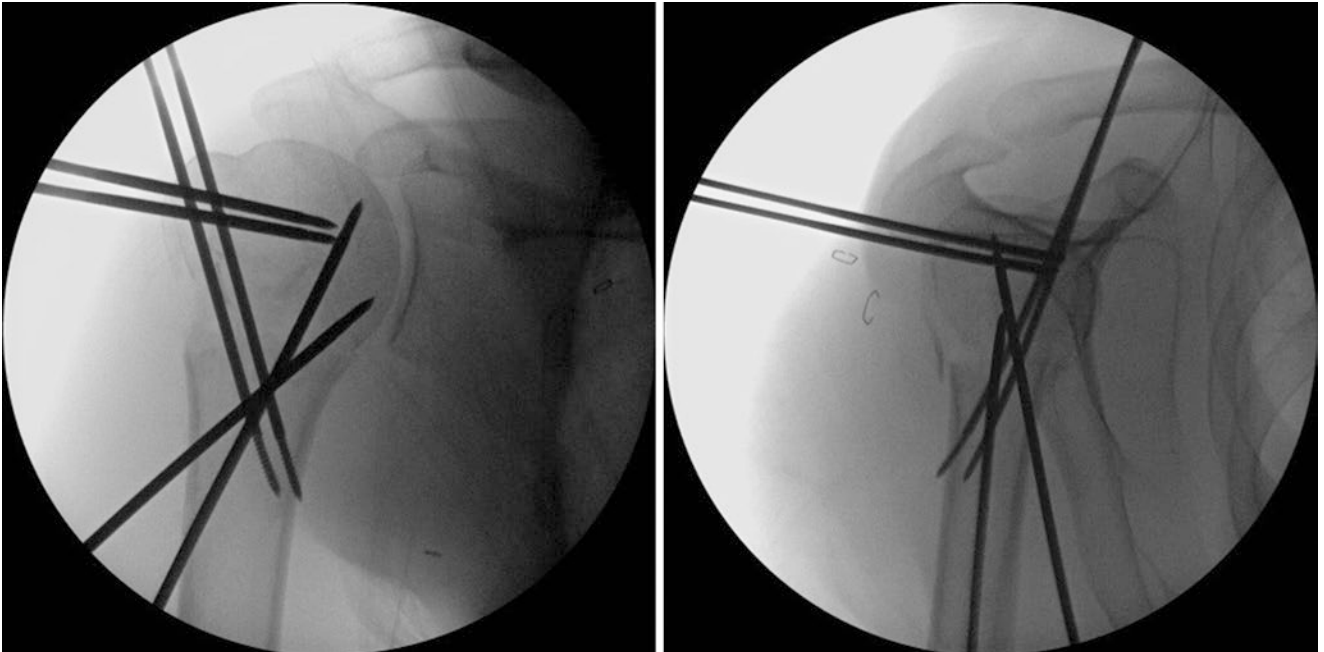


**Fig. 9.185** Greater tuberosity pins inserted down to medial neck

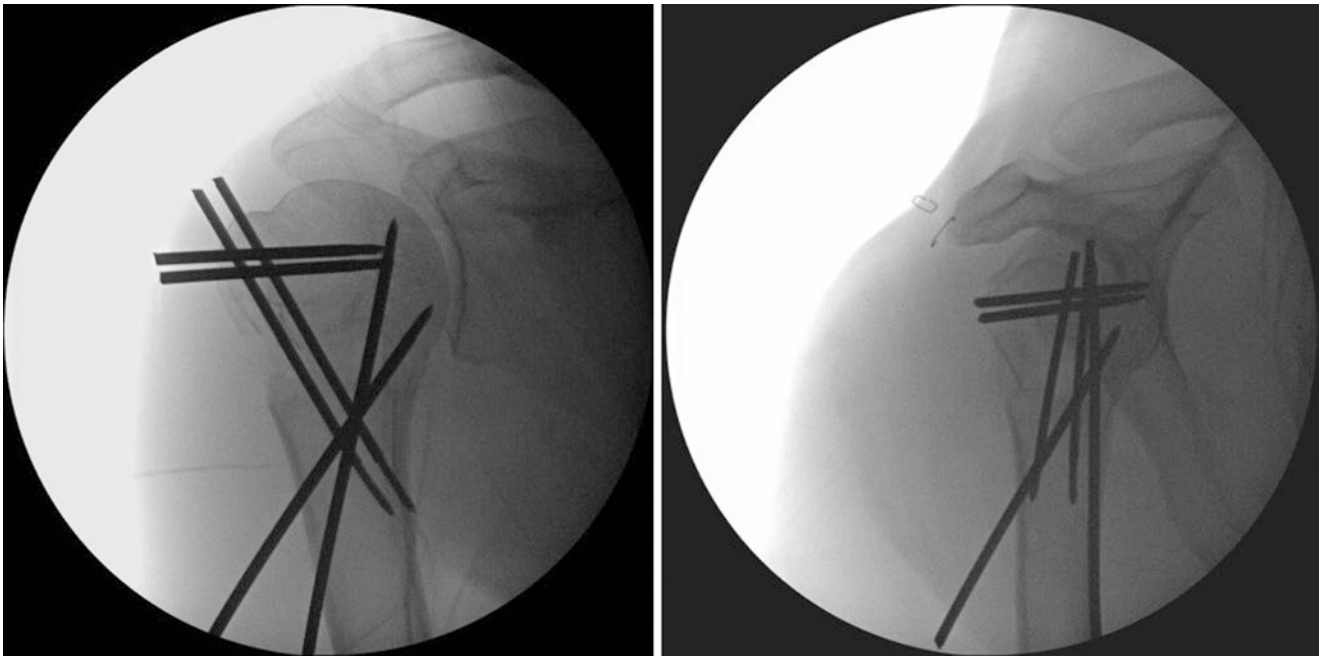




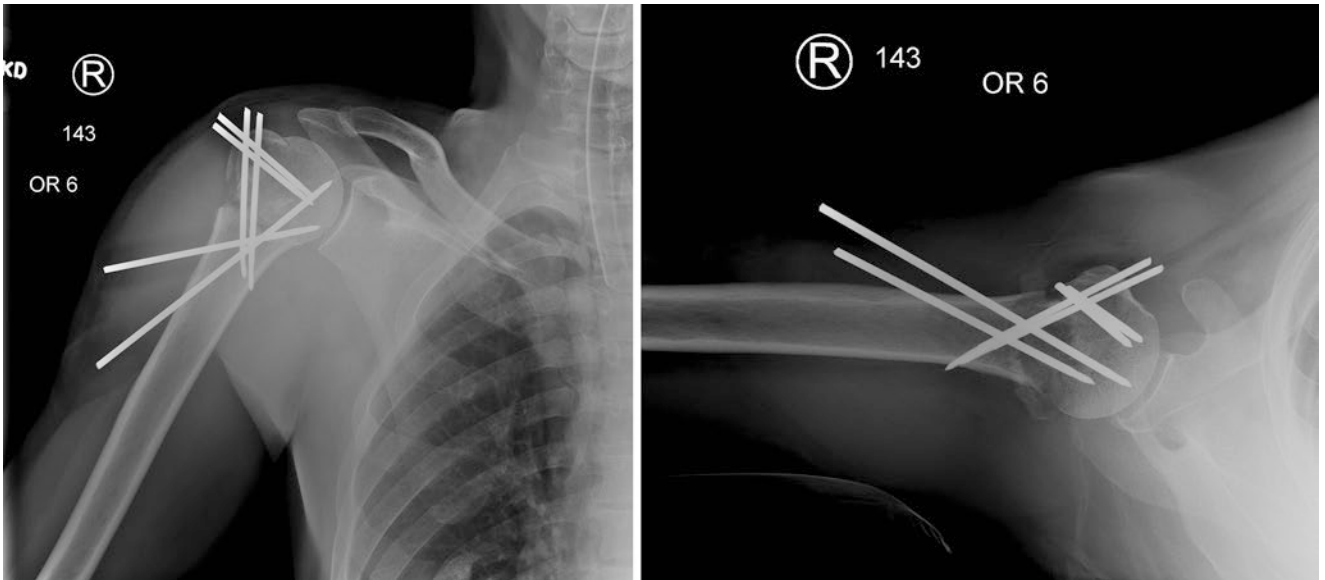
**Fig. 9.186** Position of the pins for the greater tuberosity to head fixation



**Fig. 9.187** Shaft head pins inserted



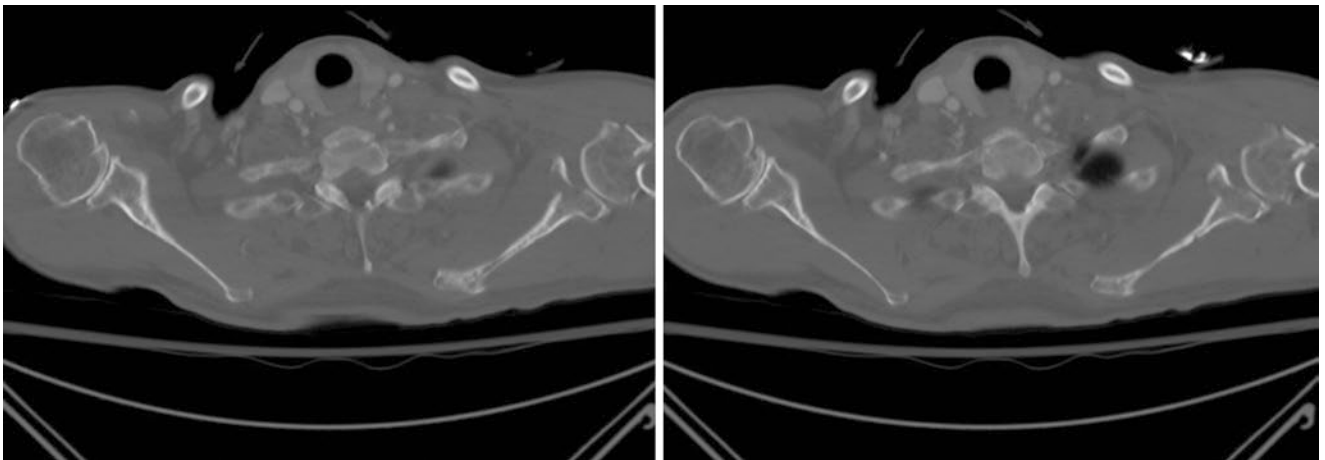
**Fig. 9.188** Threaded Steinmann pin removed



**Fig. 9.189** Postoperative radiographs



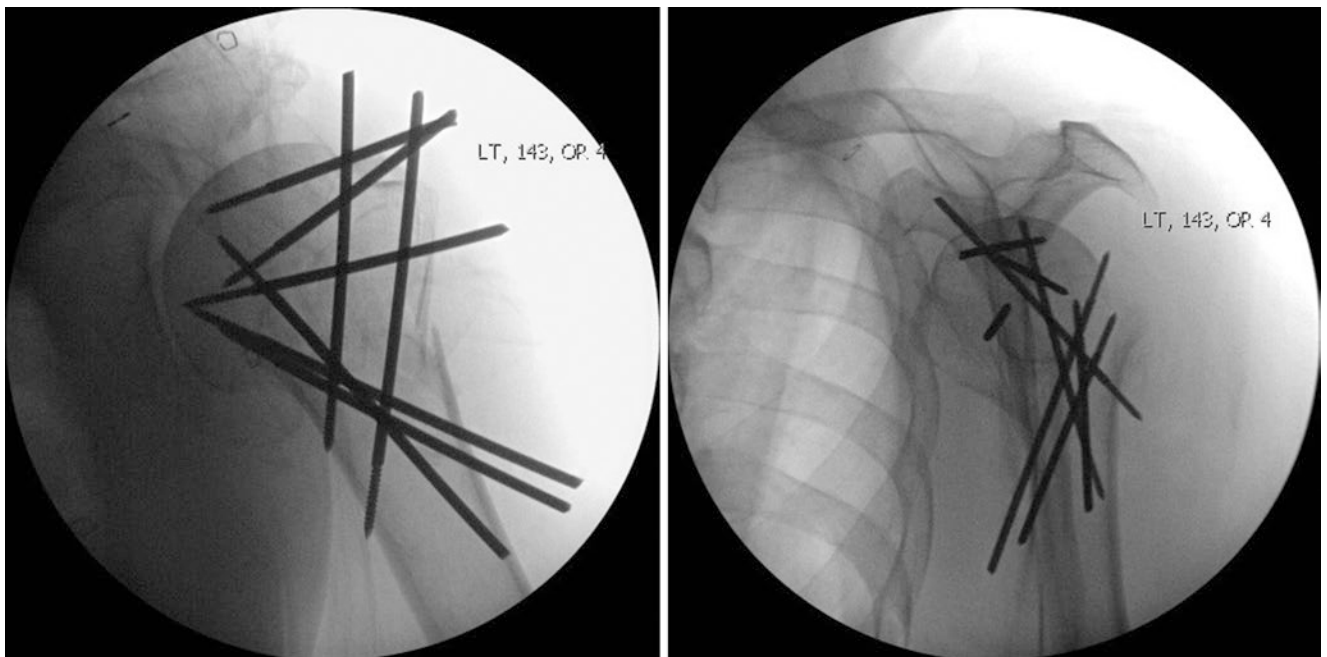
**Fig. 9.190** Radiographs of left proximal humeral fracture with anterior glenoid fracture in a hemodynamically fragile patient



**Fig. 9.191** CT scan revealing the anterior glenoid fracture



**Fig. 9.192** Coronal CT scan showing inferior subluxation of the humeral head and glenoid fracture



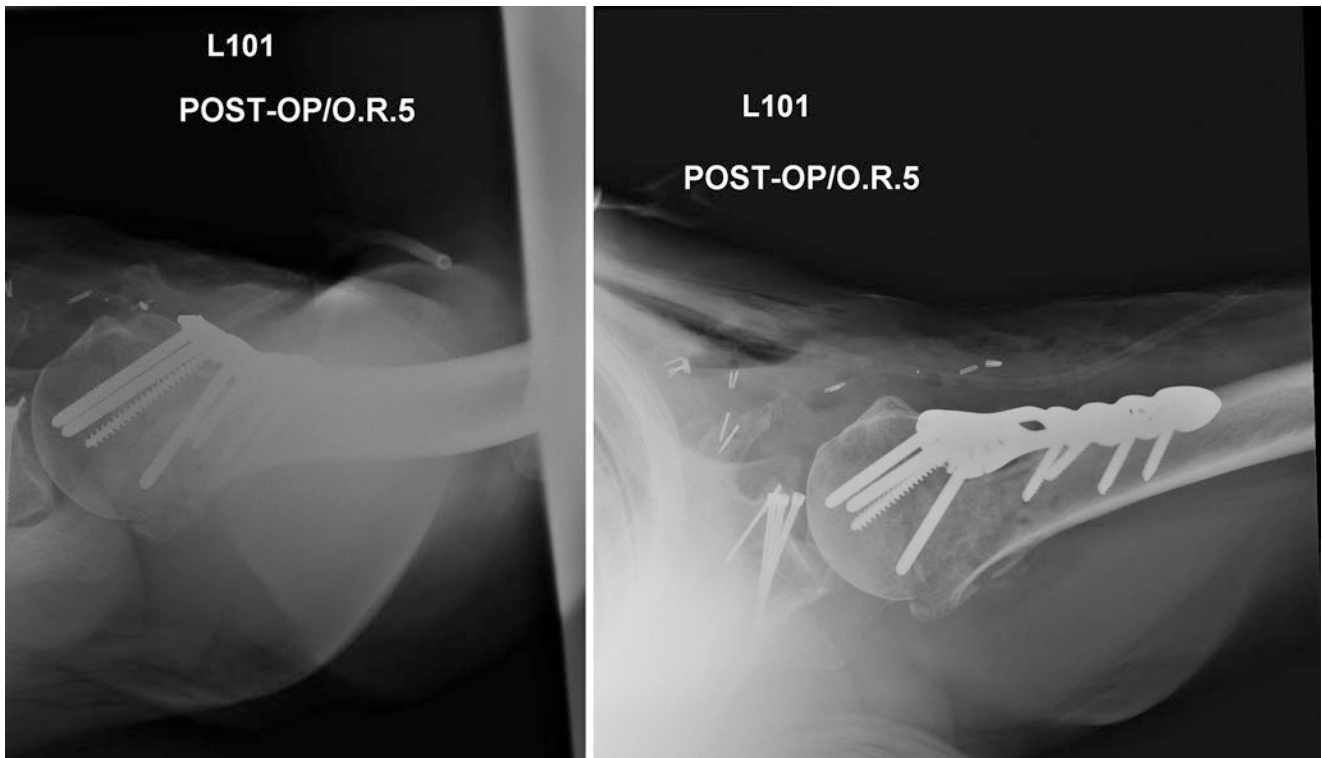
**Fig. 9.193** Temporizing percutaneous stabilization of the proximal humeral fracture; the known anterior subluxation is to be addressed later



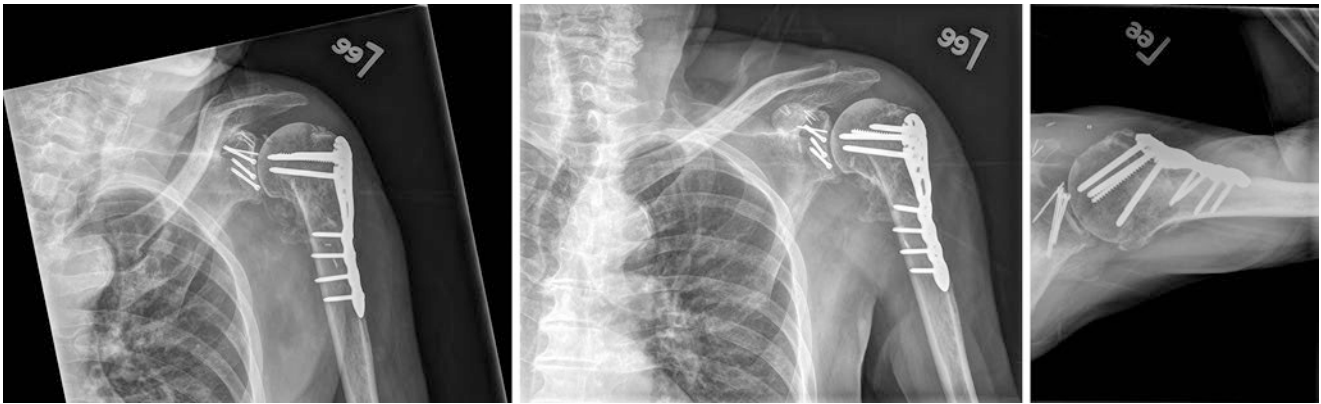
**Fig. 9.194** Radiographs demonstrating the subluxation

**Fig. 9.195** Staged anterior glenoid ORIF





**Fig. 9.196** Intraoperative axillary radiographs following ORIF



**Fig. 9.197** Follow-up radiographs. A proximal humeral plate added, as fixation of the glenoid was performed prior to adequate healing time for the head fracture. The patient returned to his manual labor job in his mid 70s



It takes 4–6 weeks for the patient's swelling to subside. As it does, the pins become prominent and will be removed in the clinic. Frequently, the more proximal K-wires come out in 3–4 weeks, largely because they trouble the patient and limit range of motion. The patient begins supported Codman's exercises 2 or 3 days postoperatively.

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## 10.1 Introduction: Treatment Criteria

It's the middle of the night. The attending physician's phone rings. A somewhat overly perky young resident announces that he/she has a patient with a closed humeral shaft fracture that's been put in a coaptation splint.

Attending: "How's the radial nerve status?"

Resident: "Okay...(Quiet) I think. I'll check it out and call you back."

Attending: "How's the alignment?"

Resident: "Acceptable."

Attending: "What's acceptable?"

Resident: (Quiet for a while) Then it comes to him/her—"Thirty degrees of varus, 20 degrees of anterior angulation."

Attending: "Do you know where *that* comes from?"

Resident: Quiet....Followed by more quiet...

The resident gave the "right answer." But it is interesting to note where orthopedically "acceptable" parameters come from. The resident's guess of 30° varus, 20° angulation comes from a paper published in 1966 by Klenerman in the *Journal of Bone and Joint Surgery*, British edition [1]. Thirty-two patients were reviewed, with 5 of the 32 having unsatisfactory results. A chart was developed. You guessed it: 30° varus and 20° anterior angulation was found to be acceptable alignment of a humeral shaft fracture. From this finding, numerous texts have perpetuated these criteria. Fortunately, the shoulder and the elbow can accommodate a large degree of nonanatomical alignment with a very functional outcome.

I've often referred to the humerus as the "ten percent bone." Whether treated operatively or nonoperatively, 10% of patients treated have a humerus that won't heal, and 10% of patients with a humeral shaft fracture will have radial nerve palsies. Of those, 10% won't recover, and 10% of those will have a nerve laceration.

With open fractures of the humerus, regardless of the status of the radial nerve, I explore the nerve to allow for its

protection during fracture debridement. I do not use radial nerve palsy as an indicator for primary exploration or consider it secondary to fracture manipulation. If I am treating a humeral shaft fracture closed with a radial nerve palsy, I get a nerve conduction velocity (NCV) study and electromyography (EMG) 3–6 weeks from the injury, and then again at 3–4 months if no clinical recovery has occurred. I will be looking for fibrillations, positive sharp waves on the report, indicating denervation, and recruitment or volitional interference, indicating recovery. To a large extent, however, I base exploration of the nerve on clinical examination. If I don't see recovery at 4–6 months, I slowly move to the operating room, having seen a number of patients recover at up to 9 months from injury.

## 10.2 Nonoperative Treatment

The standard has been nonoperative treatment with a coaptation splint, followed by a Sarmiento brace for humeral shaft fractures [2–4]. In the paper by Sarmiento *et al.* [3], which has been the basis for much of the nonoperative fracture-based treatment, a 98% union rate in closed fractures is demonstrated. But the nonunion rate may be higher than indicated, as patient follow-up was only 66%, which leaves 300 patients unaccounted for. Do not be deterred from nonoperative treatment, however, as union can be obtained even in high-energy transverse fractures.

### 10.2.1 Coaptation Splint

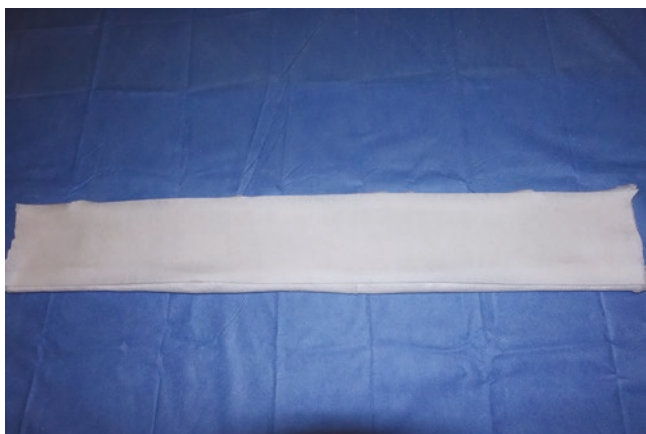
I begin with a coaptation splint made of two 4-in. plaster rolls, padded with three layers of 6-in. cast padding. I don't use 5- or 6-in. plaster rolls because they could meet at the edges and basically form a cast. Edges of the padding are turned over the plaster, and a 4-in.-wide single layer of padding is applied. The splint should be long enough to cap over the shoulder, ending in the axilla (Figs. 10.1, 10.2, and 10.3).



**Fig. 10.1** Supplies for humeral fracture coaptation splint: 4- and 6-in. cast padding, two 4-in. rolls of plaster, and two 4-in. elastic bandages



**Fig. 10.2** Three layers of 6-in. padding to length, the two rolls of plaster rolled to the same length, and one layer of the 4-in. padding



**Fig. 10.3** The plaster is dipped, placed on the 6-in. padding, the edges are rolled over, and the 4-in. padding is applied. The splint is applied with the appropriate molds; once it is hard, radiographs are obtained

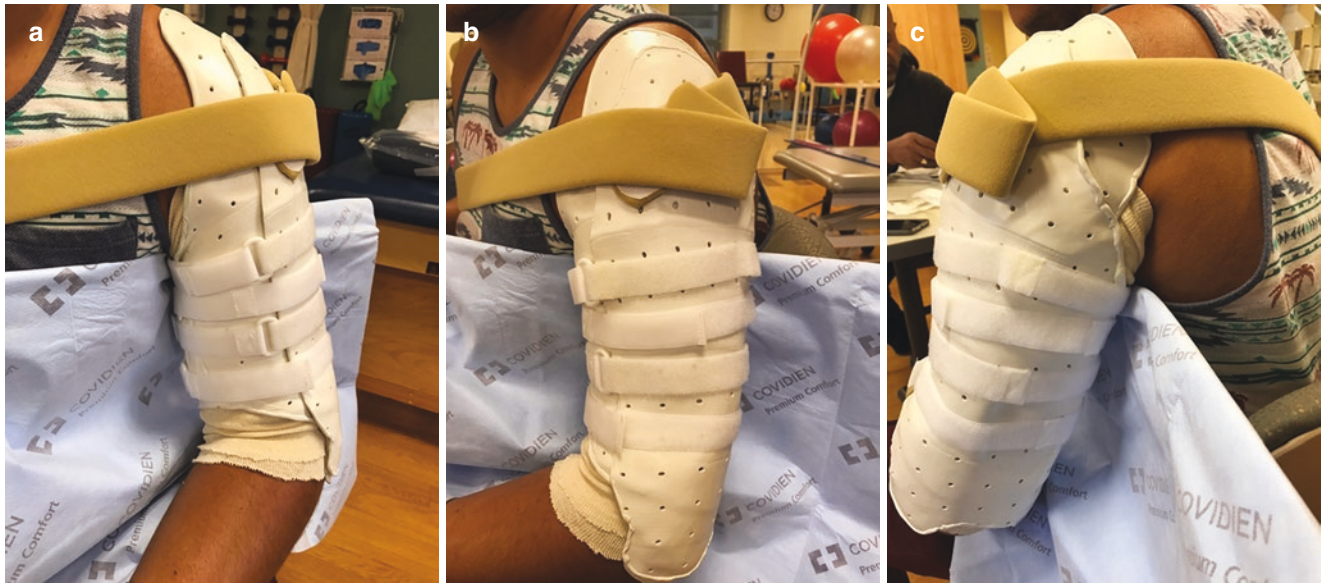
Splinting, followed by a varus correction mold, takes place after traction with the patient in a sitting position, if possible. Once applied, the coaptation splint is left in place

for 7–10 days; then the patient is transitioned to a custom Sarmiento brace. Don't rush to apply the brace. Allow swelling to decrease and let the fracture get "sticky."



### 10.2.2 Sarmiento Brace

The Sarmiento brace allows for elbow motion with active flexion and extension (Figs. 10.4 and 10.5).



**Fig. 10.4** (a) Custom humeral fracture brace for left distal humeral supracondylar fracture with long proximal oblique fracture. (b) Lateral view. (c) Posterior view

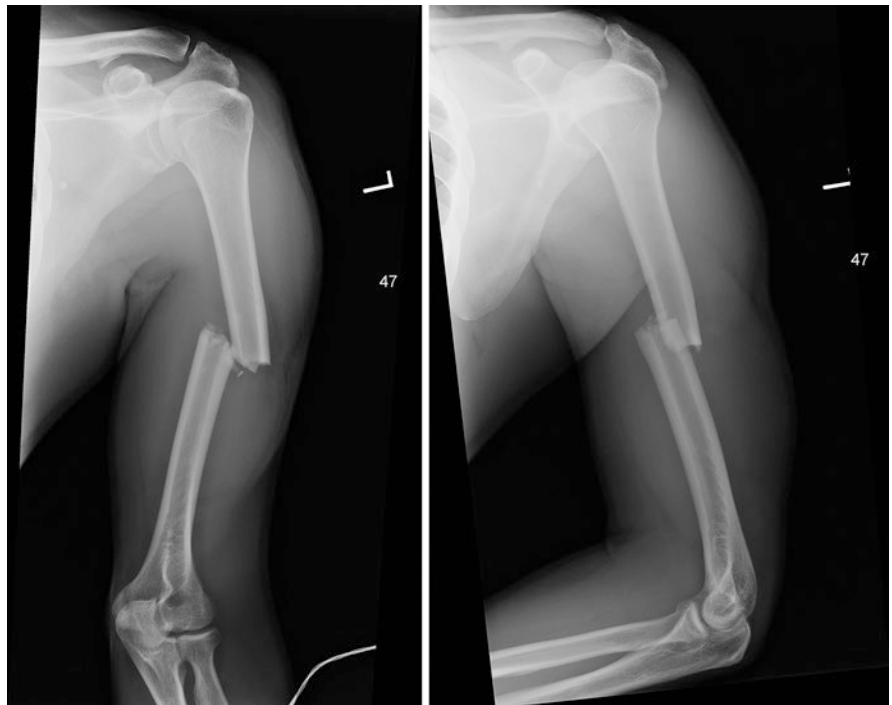
**Fig. 10.5** (a) Sling with elbow cut out to allow for some gravity-assisted reduction, along with edema glove. (b) Lateral view



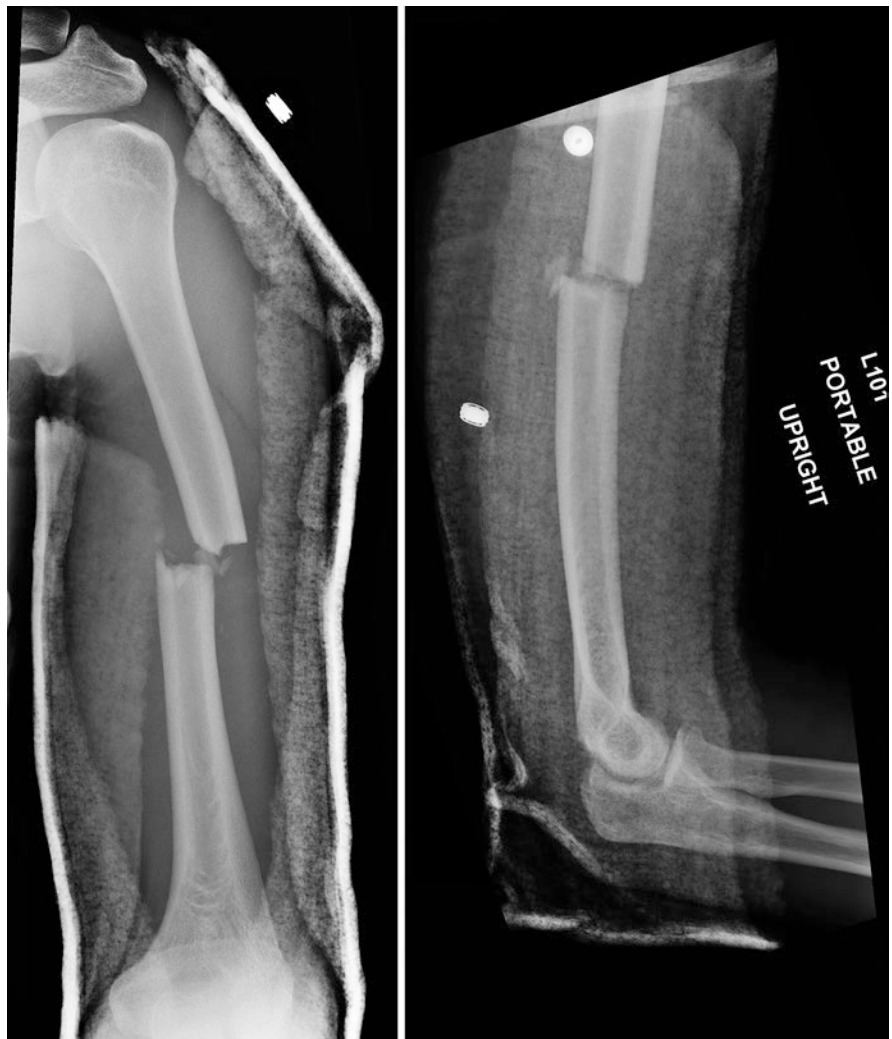
It will be worn full-time for 4 weeks. At 4 weeks, if clinical and radiographic exams indicate adequate healing, the patient is allowed range-of-motion therapy out of the brace, but it may take the humerus 6 or more weeks before adequate healing allows therapy to begin. At 2 months, the patient normally can

wean off the brace during the day. At 3 months, the brace normally is discarded. At 3–4 months, the patient can begin strengthening and weight-bearing (Figs. 10.6, 10.7, 10.8, 10.9, 10.10, 10.11, and 10.12).

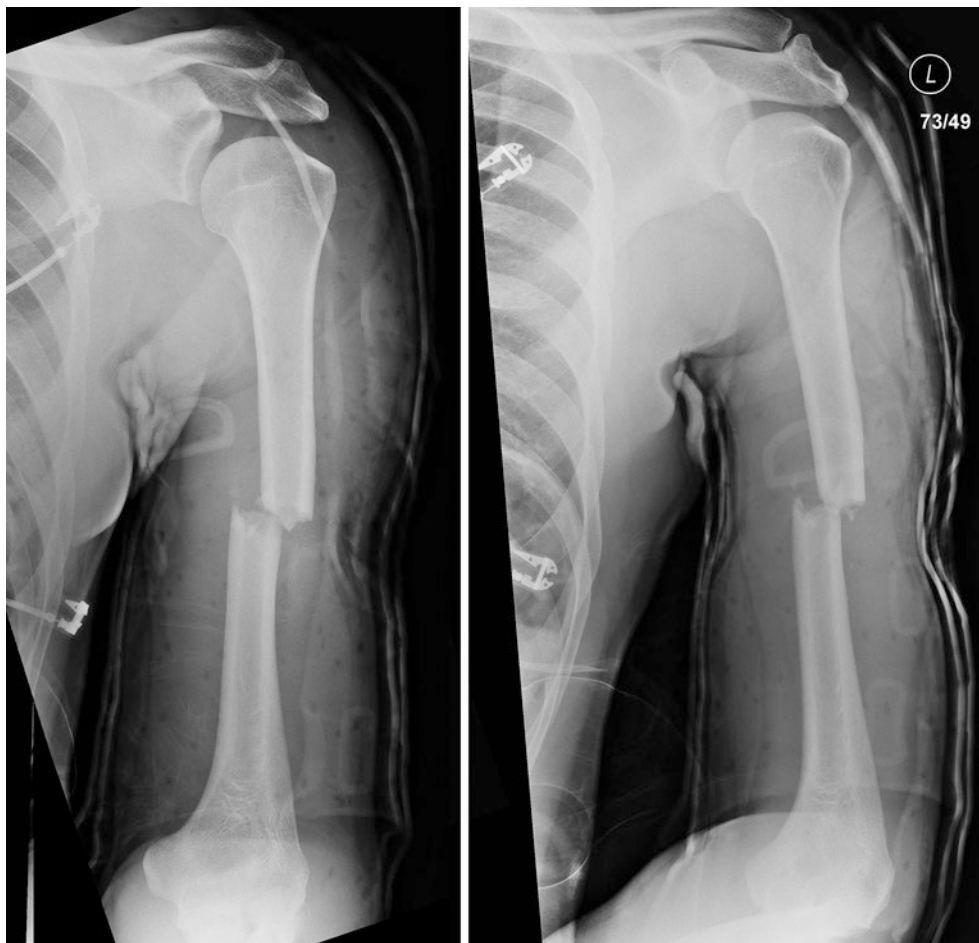
**Fig. 10.6** Injury radiographs of isolated left transverse humeral shaft fracture



**Fig. 10.7** Splinting radiographs following reduction



**Fig. 10.8** Radiographs following application of custom orthotic. Note mold at fracture site



**Fig. 10.9** Follow-up radiographs 4 weeks from injury

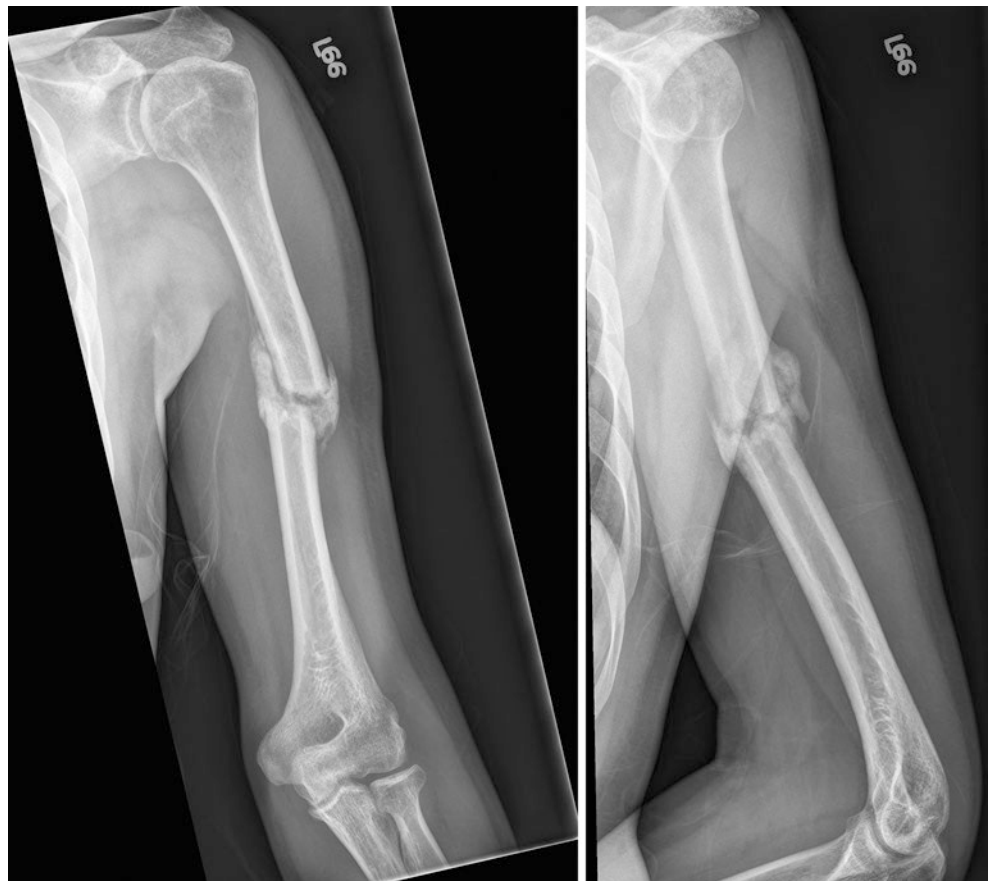




**Fig. 10.10** 2-month follow-up radiographs. Note brace tendency to slip. Callus is present



**Fig. 10.11** 4 months from injury

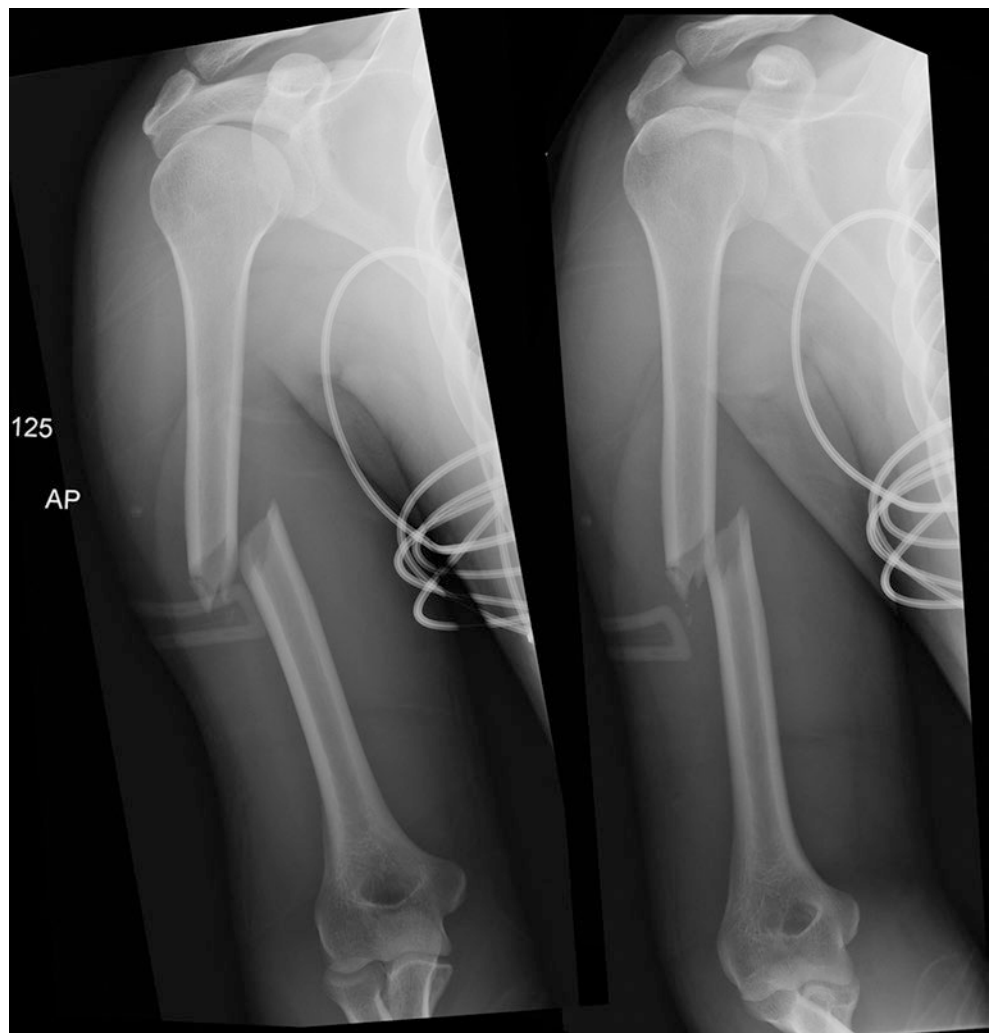


**Fig. 10.12** 6 months from injury



Do not use the off-the-shelf braces. The old adage of “One size fits none” certainly applies, and such braces almost always fall at the fracture level, slip down, block elbow

motion, and transmit the elbow motion back to the fracture (Figs. 10.13, 10.14, 10.15, and 10.16).



**Fig. 10.13** Injury radiographs of right humeral shaft fracture

**Fig. 10.14** “Off-the-shelf” fracture brace almost at level of fracture at time of referral



**Fig. 10.15** Coaptation splint applied after attempt at reduction





**Fig. 10.16** Custom orthotic applied



### 10.3 Operative Treatment

Other treatment options need to be entertained, including intramedullary (IM) fixation, unlocked or locked; external fixation; open reduction and internal fixation (ORIF) with plating; and recently, percutaneous subbrachialis plating [5–12]. Studies comparing IM nails and ORIF show similar union rates and functional outcomes (Table 10.1) [13–15].

At Shock Trauma, we treat a number of humeral shaft fractures in an operative mode, many of which would be considered for nonoperative treatment in an isolated situation. Frequently the decision is made in favor of surgical intervention to facilitate the patient's overall care, including rehabilitation and arm use, whether weight-bearing or not [16, 17]. The approach and subsequent fixations will be further outlined.

**Table 10.1** Humerus fracture healing rate

Author	Year	Fractures (n)	Treatment	Union (%)
Brumback <i>et al.</i> [5]	1986	58	IM nails (Rush rods or Ender nails)	94
Hall and Pankovich [6]	1987	86	Ender nails	99
Mostafavi and Tornetta [9]	1997	18 open	External fixation	94.4
Shazar <i>et al.</i> [7]	1998	94	Ender nails, retrograde	91.5
Chapman <i>et al.</i> [14]	2000	46	ORIF	93
		38	IM nails	87
McCormack <i>et al.</i> [13]	2000	22	ORIF	95
		19	IM nails	89
Sarmiento <i>et al.</i> [3]	2000	465 closed	Functional brace	98
		155 open		94
Denard <i>et al.</i> [10]	2010	–	Nonoperative	79
		–	Operative	91.3
Ali <i>et al.</i> [4]	2015	120	Nonoperative	83
				76
		Proximal third		
				88
		Middle third		
		Distal third		85

IM intramedullary, ORIF open reduction internal fixation

### 10.3.1 Plate Fixation Versus Intramedullary Nailing For Humeral Shaft Fractures

In general, I prefer plate fixation for humeral shaft fractures. I have used external fixation in select cases. I use IM nails in

pathologic fractures, fractures associated with soft tissue issues, and fractures with extensive comminution, but IM nails can be difficult to use in humeral shaft fractures. Be wary of the notion of easy, quick nailing (Figs. 10.17, 10.18, 10.19, 10.20, 10.21, 10.22, 10.23, 10.24, 10.25, and 10.26).



**Fig. 10.17** Metastatic pathologic right humeral shaft fracture



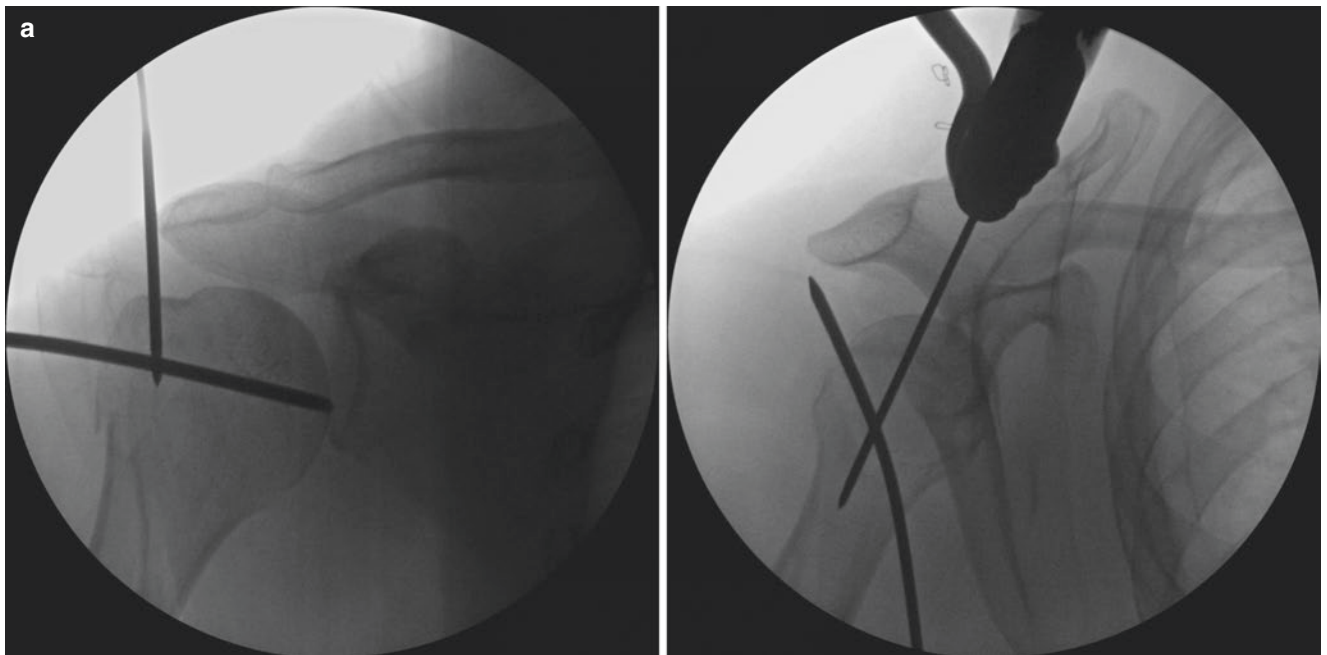
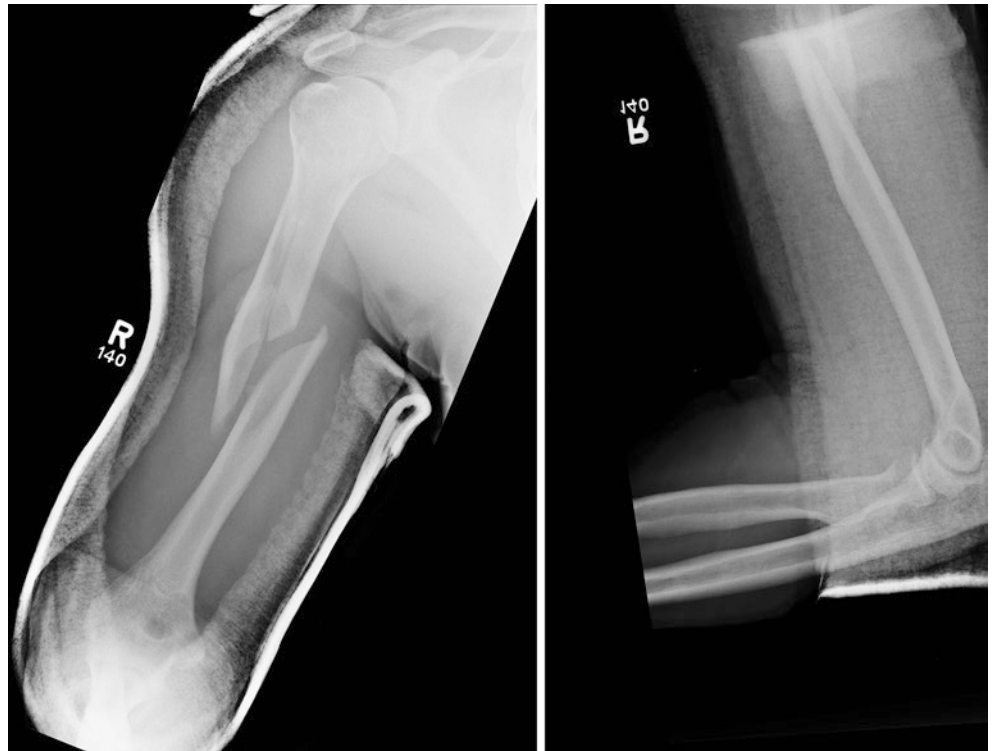


**Fig. 10.18** Radiographs following intramedullary fixation

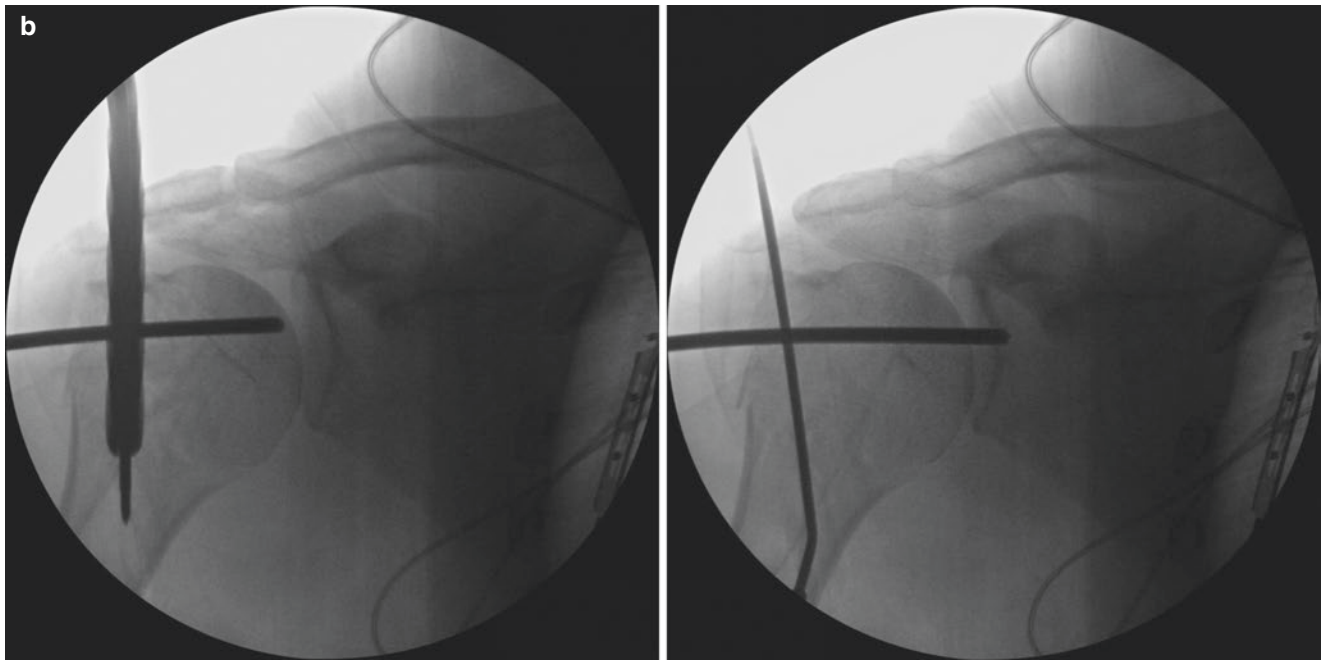


**Fig. 10.19** Injury radiographs of comminuted right humeral shaft fracture

**Fig. 10.20** Radiographs following reduction and splinting. Lower extremity fractures influenced decision for surgical intervention to allow use, albeit no weight bearing because of the proximal extent of the fracture



**Fig. 10.21** (a) Intramedullary fixation selected. Note threaded Steinmann pin utilized for joystick and prevention of greater tuberosity fracture propagation. Lateral starting point of C-collar limiting shoulder access. (b) Over-reamer inserted, followed by guide wire



**Fig. 10.21** (continued)



**Fig. 10.22** Radiographs of healed fracture at time of discharge



**Fig. 10.23** Injury radiographs of segmented left humeral shaft fracture



**Fig. 10.24** Radiographs following intramedullary fixation with Synthes Spiral Blade



**Fig. 10.25** Axillary lateral radiograph, showing that the blade should be pointing more posterior



**Fig. 10.26** Grashey shoulder radiograph, demonstrating starting point and insertion medial to the cephalic sulcus

The surgical approach to the humeral shaft fracture is predicated upon the level of the injury. Generally, for fractures just proximal to the mid-humerus, I utilize an anterior or anterior lateral approach. With fractures at the mid to distal humerus level, I prefer a posterior approach.

### 10.3.1.1 The Anterior Approach

The anterior approach has some disadvantages. First, the incision is particularly unpleasant, and because of the skin tension lines, it tends to spread. This can be particularly bothersome to women.

Another issue is that the surgical plane involves splitting a muscle, the brachialis. I prefer not to split any muscle. The deltoid is taken off of the deltoid insertion and continued down into the brachialis, such that the deltoid brachialis is effectively maintained in continuity as a sleeve, which facilitates the maintenance of tension for both muscles. Papers have been written concerning a subbrachial approach with brachialis innervation descriptions inconsistent with my findings [11]. Generally, there are two or three perforators from the musculocutaneous nerve, which comes from the medial side to the lateral side; I try to preserve and effectively work through these windows. There is a purported dual innervation to the brachialis, radial, and musculocutaneous, but the perforators are quite large, and I don't understand why they would be there if not needed. One report demonstrated dual innervation of the brachialis in 50% of dissections [18]. Therefore, half the time, the brachialis is totally dependent on the musculocutaneous nerve for innervation. Thus I try to preserve as many neurovascular pedicles as possible. How important is the lateral half of the brachialis to elbow flexion with an intact biceps, brachioradialis, and half of the brachialis? Seems a little philosophical. My position is to preserve the pedicles and work through pedicle windows.

The third point of dislike regarding the anterior and anterolateral approach is that the plate fixation is effectively 90° to the major moments of stress applied to the humerus, specifically flexion/extension. The orientation of the screws

would therefore be positioned to potentially toggle if enough force in flexion and extension is applied. Having noted this concern, however, I cannot say that I've had problems secondary to this concept.

Fourth, if distal fixation and exposure is required, dissection can be difficult, particularly when trying to find the radial nerve. Because the brachioradialis and the brachialis muscles seem to blend together, I believe this interval can be one of the most difficult to define. Sometimes you are fortunate, and perforators from the posterior radial collateral arterial system course through this interval, which will give you a path to the nerve. I've never been a fan of "Oh...It's over there." I like to see structures of importance when I'm in the neighborhood. The proximity of the radial nerve to the supracondylar region of the distal humerus can be humbling, and an aberrantly placed retractor could be problematic. Also, retracting the biceps allows visualization of the musculocutaneous nerve, becoming the lateral antebrachio-cutaneous nerve, crossing from medial to lateral, so don't let this be a source of confusion: This is not the radial nerve.

If I am using an anterolateral approach, my rule of thumb for plate selection concerns whether I can get at least two cortical screws into the proximal shaft neck; if I can, then I will use a locking plate with two locking screws parked in the head and four screws distal to the fracture. These patients are not allowed weight bearing for 6 weeks. If I can't get two screws into the neck, I use a long proximal humerus locking plate. Distal to this, I use a nonlocking 3.5-mm plate or (in a larger individual) a 4.5-mm narrow plate. These patients usually are allowed immediate weight bearing. The setup for these cases is the same as for the proximal humerus, with the incision swept distally lateral, then back slightly medially towards the antecubital fossa. I will use a sterile tourniquet at times to allow radial nerve identification in the more distal fractures, when retractors may be placed around the humerus during plating. (Figs. 10.27, 10.28, 10.29, 10.30, 10.31, 10.32, 10.33, 10.34, 10.35, 10.36, 10.37, 10.38, 10.39, 10.40, 10.41, 10.42, 10.43, 10.44, 10.45, 10.46, 10.47, 10.48, and 10.49).



**Fig. 10.27** Anterolateral incision outlined from clavicle to antecubital fossa. The length is dictated by the location of the fracture. (Constricted area is a consequence of cadaver preparation)

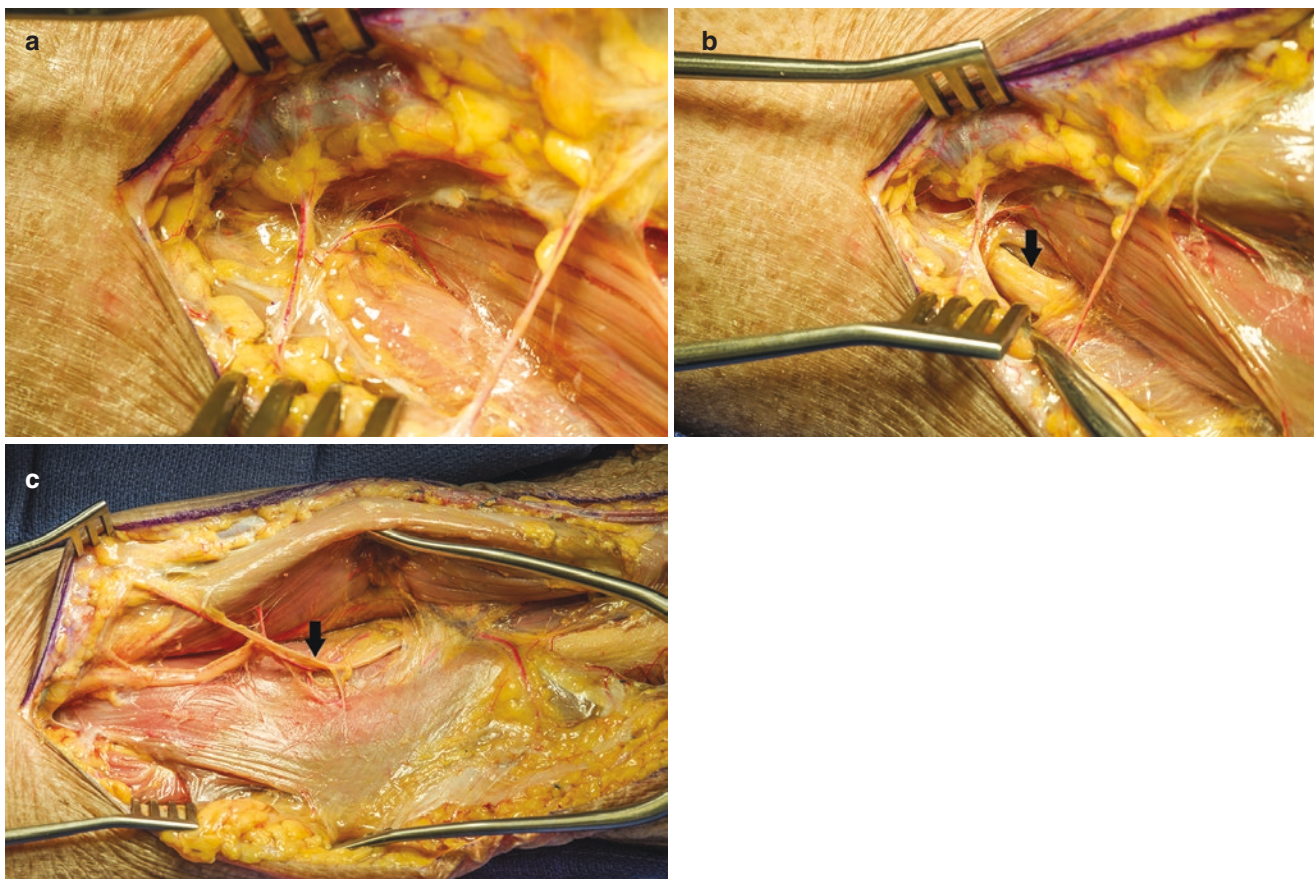


**Fig. 10.28** Proximal portion of deltopectoral approach. Tributaries to the cephalic vein are identified, clipped, and divided



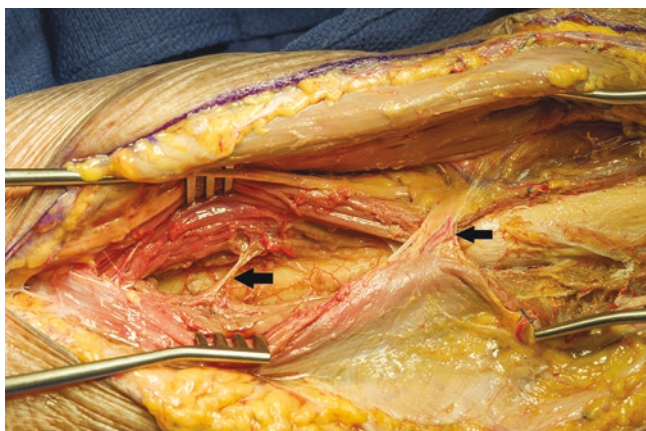


**Fig. 10.29** Incision extended distally with cephalic vein tributaries divided after clip application, maintaining the vein medially



**Fig. 10.30** (a) Perforators distally utilized to help identify the radial nerve in the brachialis/brachioradialis interval. (b) Radial nerve (*arrow*). (c) Musculocutaneous nerve (*arrow*) between the biceps brachii and the brachialis

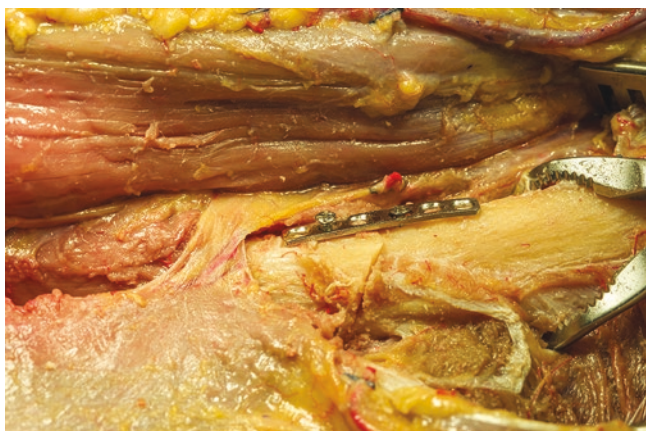




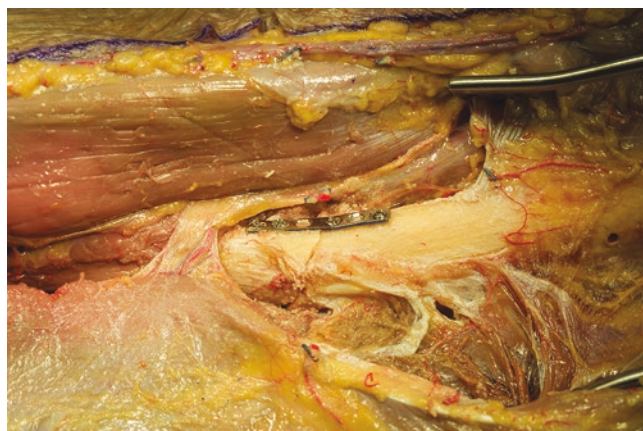
**Fig. 10.31** Brachialis split with the lateral portion in continuity with the deltoid proximally. Perforators and pedicles (*arrow*) from the musculocutaneous nerve to the lateral portion of the brachialis



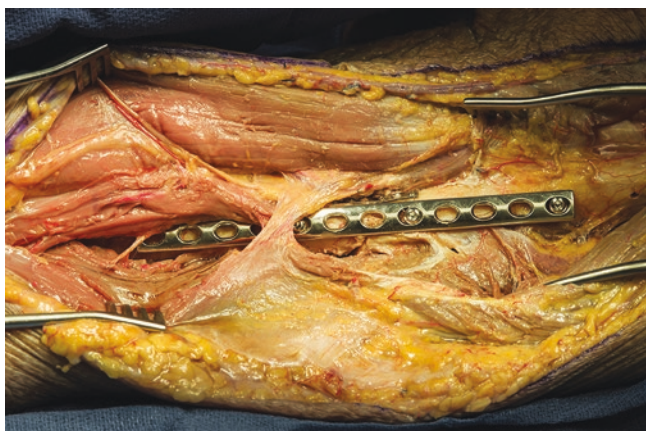
**Fig. 10.32** Expanse of the humerus accessible with this approach



**Fig. 10.33** Humerus osteotomized (fractured) with provisional fixation with 2.0-mm mini-fragment plate in a compression mode to create an axilla. Note eccentric screw positioned in plate in distal fragment

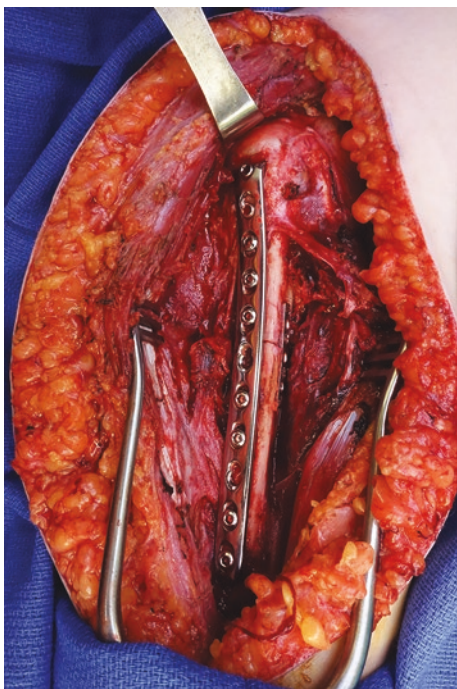
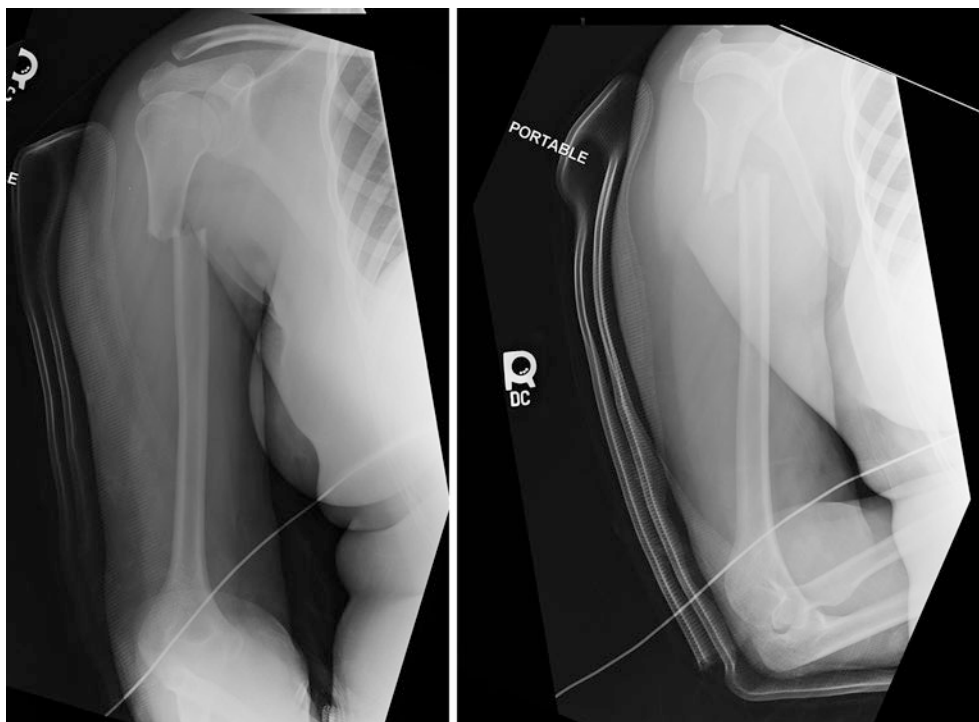


**Fig. 10.34** Provisional plating completed



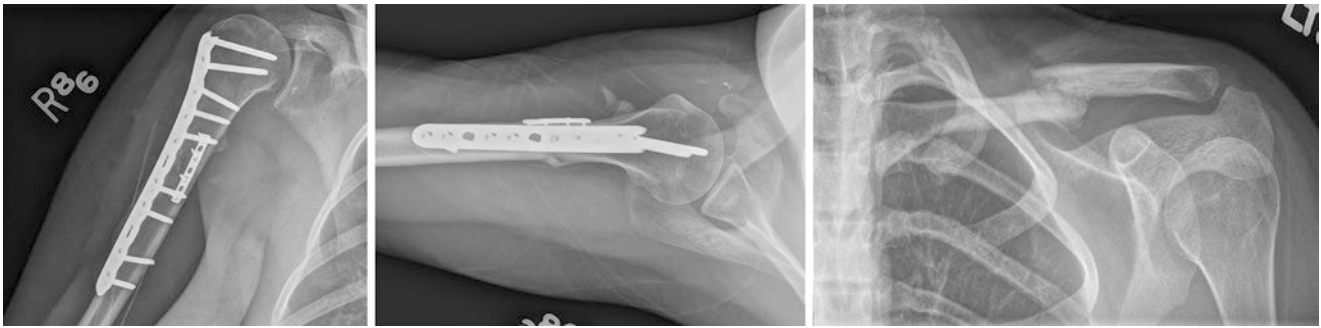
**Fig. 10.35** Definitive plate fixation with 3.5-mm plate in compression even with mini-fragment plate. Fixation performed through perforator/pedicle windows. (Not all screws have been inserted)

**Fig. 10.36** Injury radiographs of right proximal humeral shaft fracture



**Fig. 10.37** Final fixation through anterolateral approach, with top of plate cut off in situ to avoid impingement

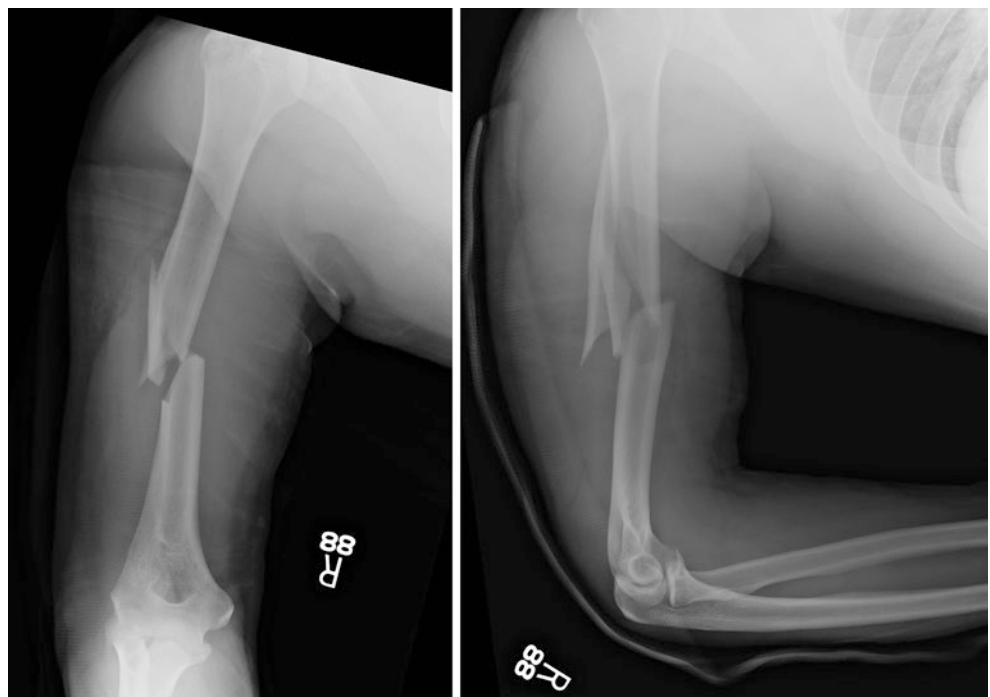




**Fig. 10.38** Radiographs at time of discharge, including nonoperatively treated left clavicle fracture



**Fig. 10.39** Initial injury radiographs from outside hospital, showing right humeral shaft fracture

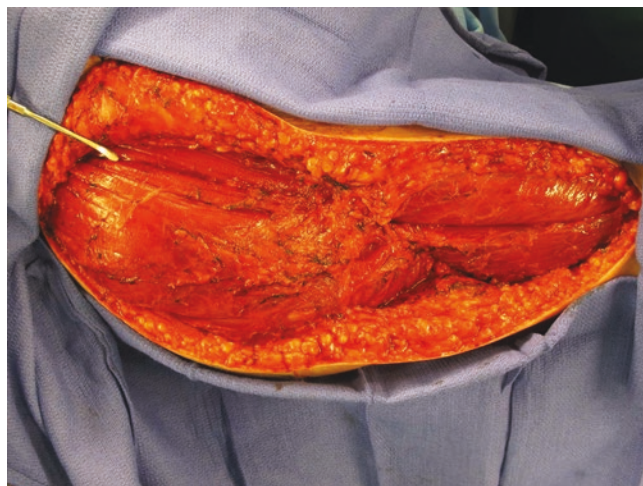


**Fig. 10.40** Radiographs following reduction and splinting

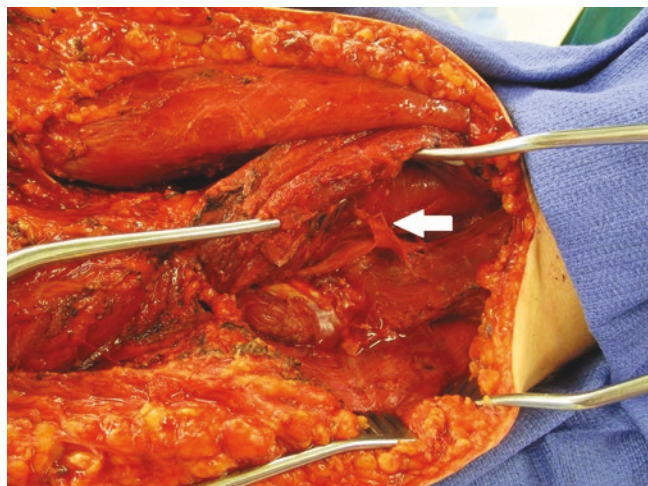




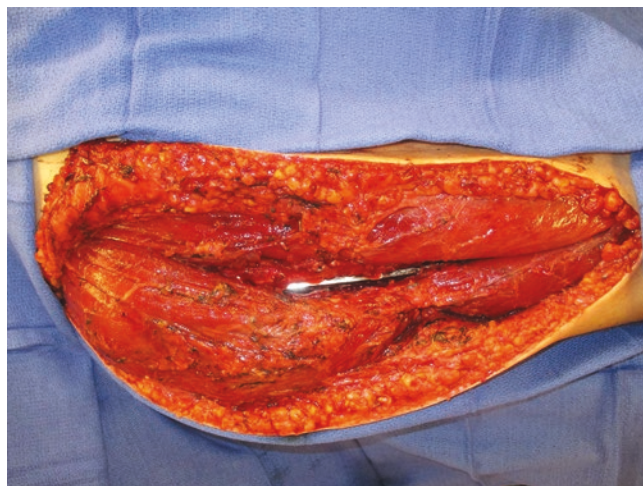
**Fig. 10.41** CT scan demonstrating proximal humeral neck and greater tuberosity fracture



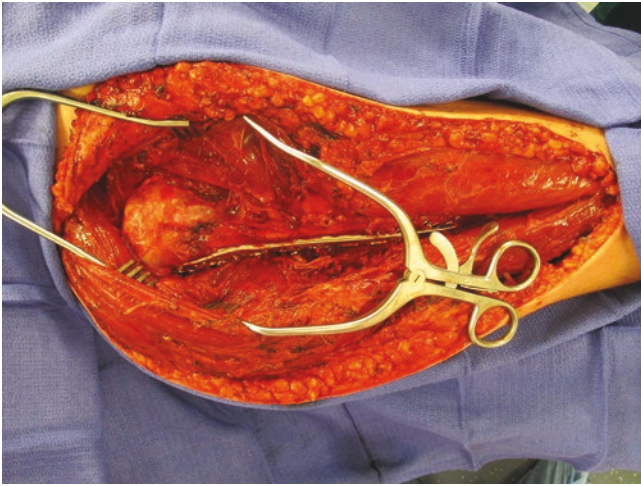
**Fig. 10.42** Anterolateral approach with Freer pointing to deltopectoral interval



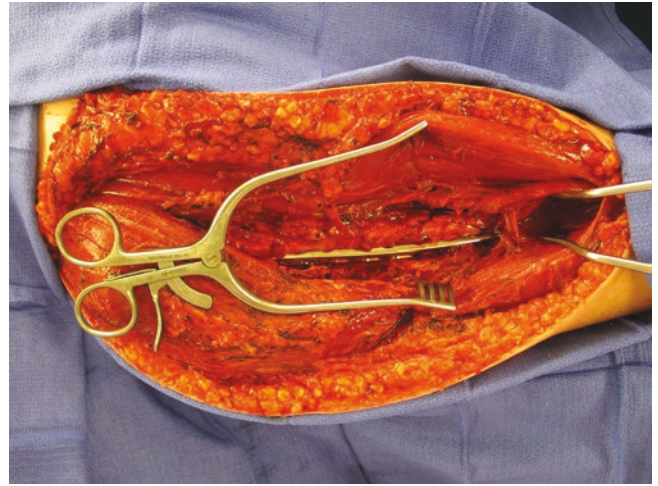
**Fig. 10.43** Distal dissection with perforators (*arrow*) leading to the radial nerve



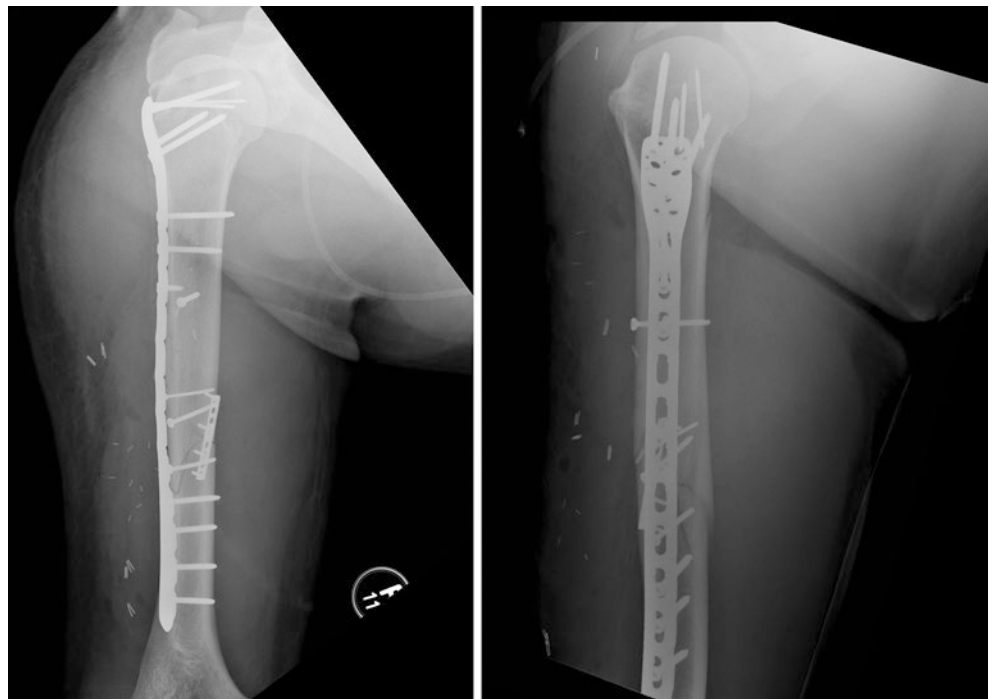
**Fig. 10.44** Deltoid and lateral portion of the brachialis elevated in continuity



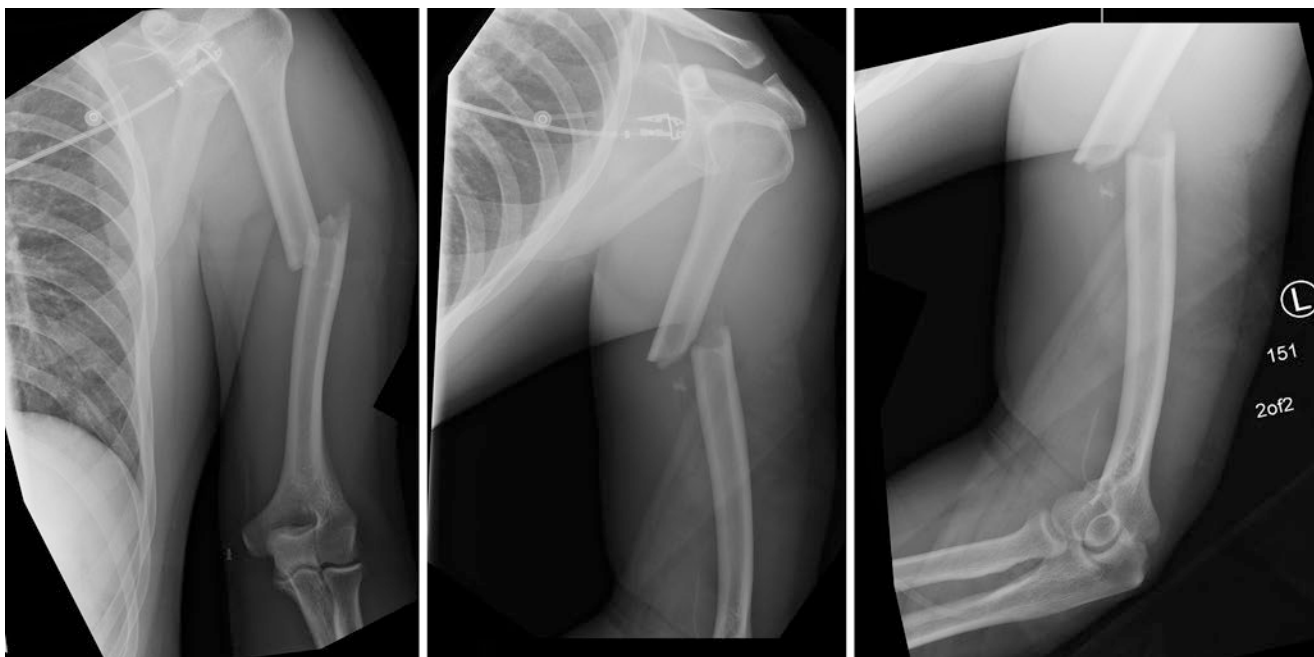
**Fig. 10.45** Proximal fixation



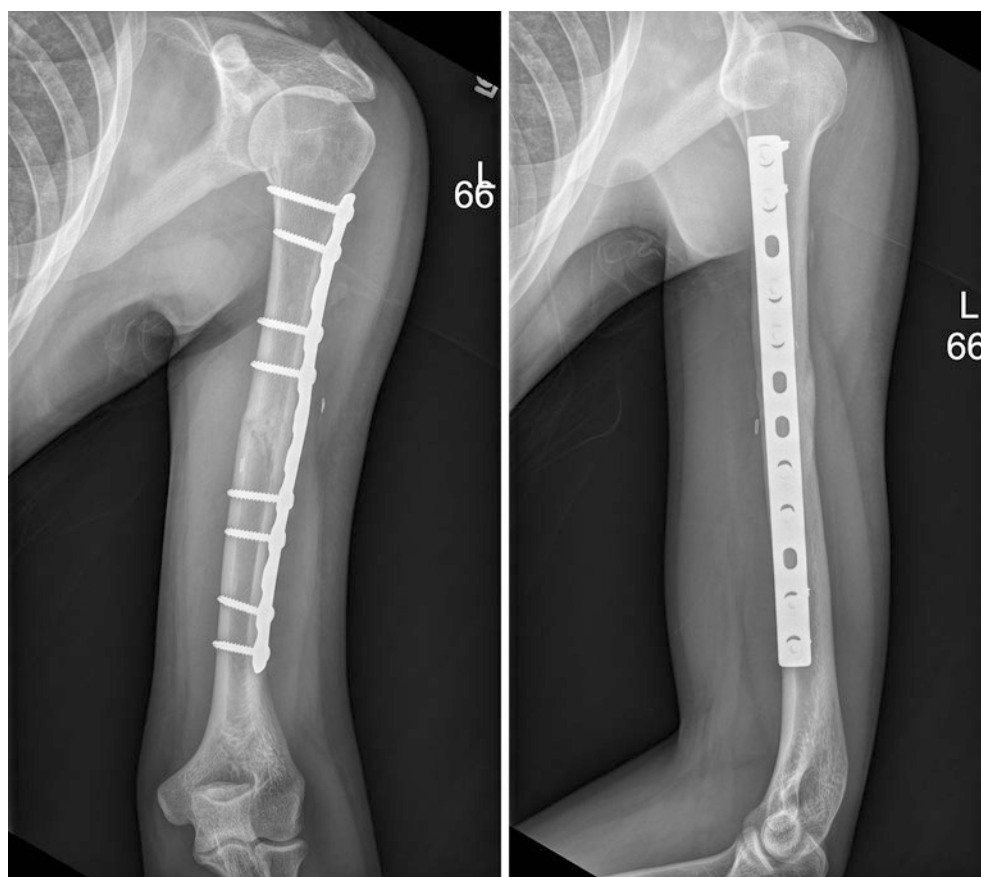
**Fig. 10.46** Distal fixation with neurovascular pedicle to lateral portion of the brachialis



**Fig. 10.47** Intraoperative radiographs following open reduction and internal fixation (ORIF)



**Fig. 10.48** Injury radiographs of left humeral shaft fracture



**Fig. 10.49** Radiographs of healed fracture with 4.5-mm plate, which was selected because of the patient's size and associated injuries



I do not do subbrachialis percutaneous plating even though I know the reported results, because I am concerned about potential nerve injury.

### 10.3.1.2 The Posterior Approach

In general, I prefer the posterior approach. I believe that the incision is clinically more acceptable. The triceps can be mobilized medially, as described in *The Techniques of Hand Surgery* and the work by Gerwin *et al.* [19, 20]. I do not split the triceps. The plate can be placed on a relatively flat surface and short of the axillary nerve proximally; the fixation can go from the surgical neck down to an intra-articular level on a relatively flat surface. I believe that patients rehabilitate better following the posterior approach.

The posterior humeral approach is used preferentially for most mid to distal fractures, and occasionally, depending on the fracture pattern, this approach can be used for a slightly more proximal fracture to the mid portion of the shaft. This setup and approach can also be used for supracondylar, transcondylar, and intercondylar fractures.

The patient is placed in a lateral position on a beanbag, with an appropriate axillary roll. A padded Mayo stand is utilized to maintain the arm in extension for a couple of reasons. I do not like the arm to be in a dependent position, for reasons of both sterility and swelling. Also, with extension and the distal positioning of the plate, there is an internal check: If the arm is in the extended position and if the plate is not hitting the radial head, you know that when the patient extends the elbow, this will not be a problem.

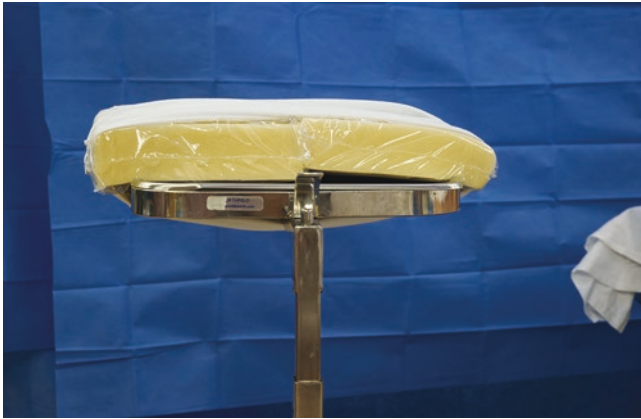
The prep and draping are performed with the arm suspended, followed by application of a sterile tourniquet after the povidone-iodine (Betadine) is removed with alcohol. I like to apply the tourniquet with the arm suspended, to minimize the potential for telescoping the arm; I believe that telescoping can cause secondary injury, particularly to the radial nerve (Figs. 10.50, 10.51, 10.52, 10.53, 10.54, 10.55, 10.56, 10.57, 10.58, 10.59, 10.60, 10.61, 10.62, 10.63, 10.64, 10.65, 10.66, 10.67, 10.68, 10.69, and 10.70).



**Fig. 10.50** “Patient” positioned on beanbag with suction nozzle on the side of the injured arm



**Fig. 10.51** Arm suspended prior to turning patient



**Fig. 10.52** Padded Mayo stand with hook utilized to wrap a laparotomy sponge around the wrist and secure it to the stand to prevent motion after the arm is positioned. (This used to be the job of the medical student)



**Fig. 10.53** Draped Mayo, with tape securing cover so it doesn't walk up the stand



**Fig. 10.54** Patient positioned lateral with up leg forward and down leg back to prevent the patient from rolling back supine

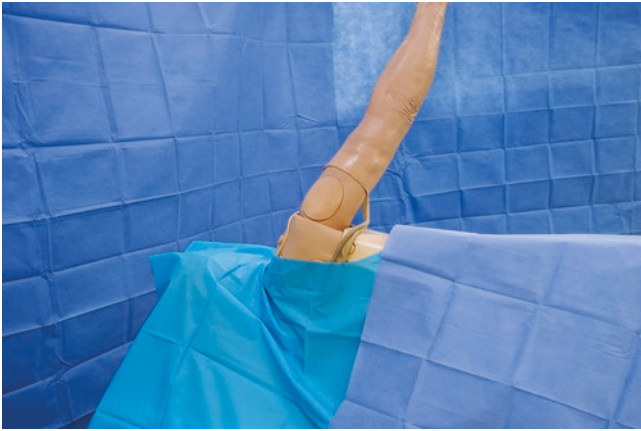


**Fig. 10.55** Axillary roll, gel roll positioned



**Fig. 10.56** Sticky split U-drape followed by four absorbent barriers taped to each other. (This is the only positioning in which I use a sticky split U-drape. I don't use them on the hand table, because the drapes can slip around on the split, which can be annoying when doing microscopic surgery)





**Fig. 10.57** After prepping with povidone-iodine (Betadine), the barriers are removed and a body drape is placed over the body



**Fig. 10.58** Three-fourths reinforced drape over down arm

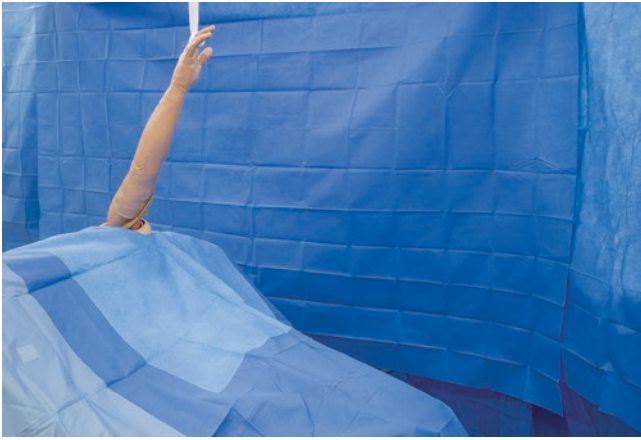


**Fig. 10.59** Four blue towels applied with staples



**Fig. 10.60** Split sheet with tails brought anteriorly

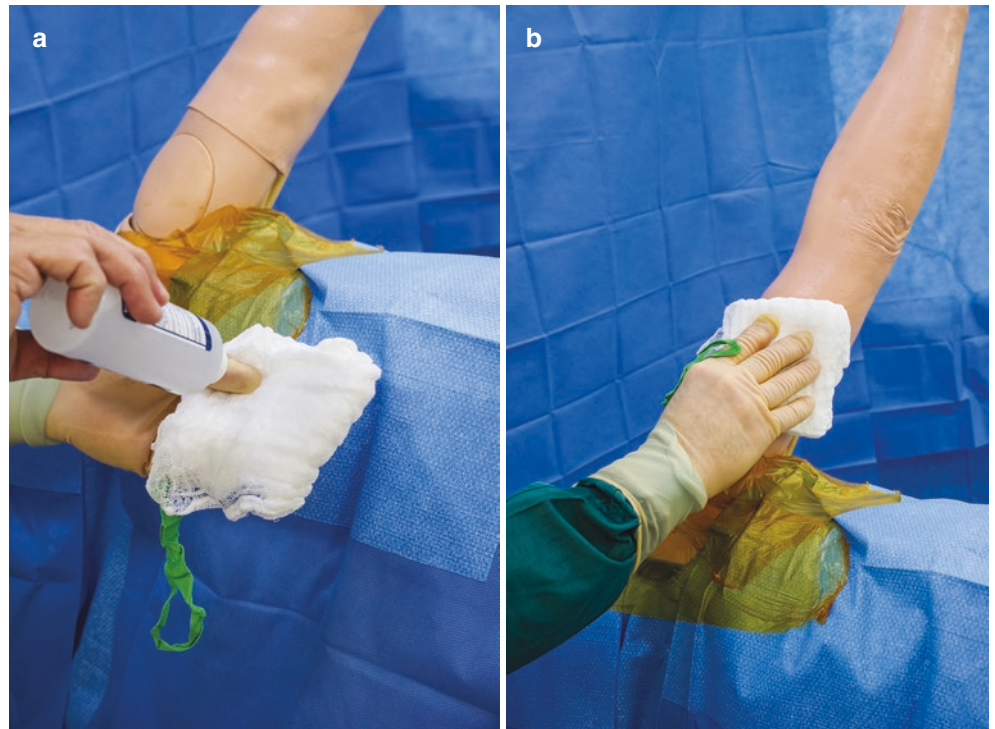




**Fig. 10.61** Second split sheet with tails going to the back



**Fig. 10.62** Ioban® around the perimeter. (In some images, the Ioban® is not shown on the skin because it does not readily come off the “volunteer”)



**Fig. 10.63** (a, b) Alcohol is used to remove the Betadine prior to tourniquet application; the Betadine is removed to prevent “burns” under the tourniquet. The Ioban® strips should be applied prior to the alcohol usage because the Ioban® doesn’t stick well if the alcohol gets in the drapes



**Fig. 10.64** Sterile tourniquet: 18" with 6" padding. Hoses over the back of the patient



**Fig. 10.65** The padding is split and turned down to help prevent tourniquet migration

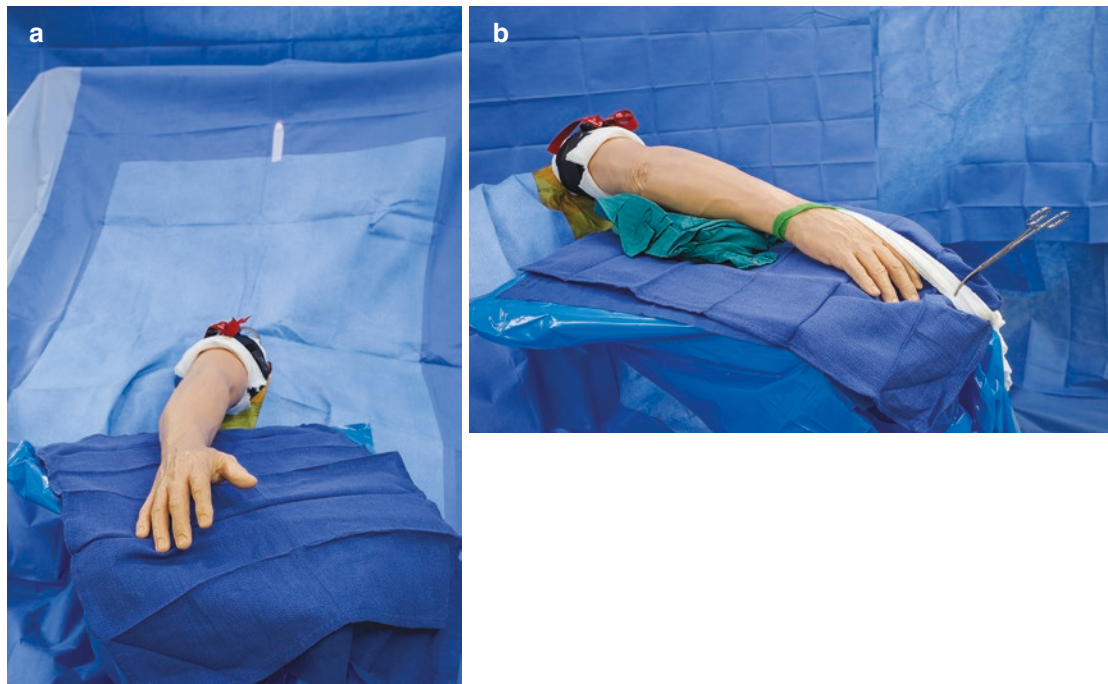


**Fig. 10.66** Hand down from suspension and finger painted



**Fig. 10.67** Third split for anesthesia barrier. The small strip has not been pulled off the drape, so that the tourniquet hoses will slide





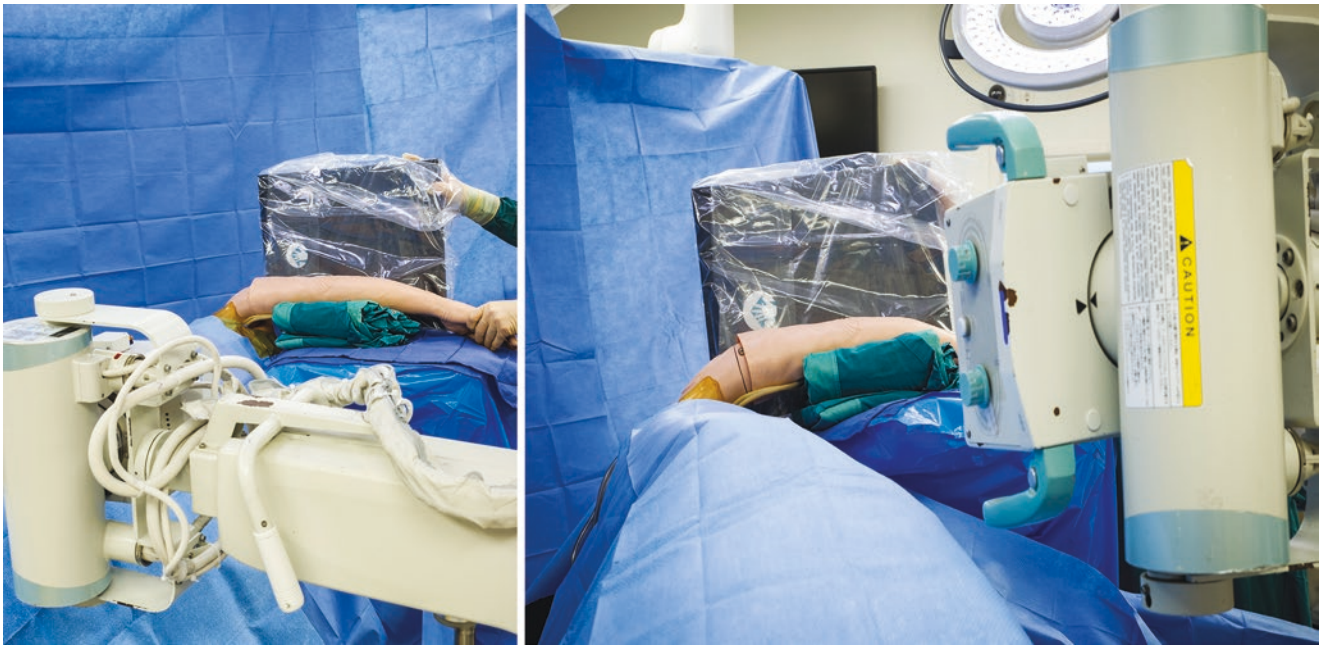
**Fig. 10.68** (a) Anesthesia drape up, arm on padded Mayo. (b) After the skin incision is marked, the arm is elevated, and the tourniquet is inflated, the arm is secured to the Mayo stand with a lap (laparotomy

sponge) and usually an ABD pad around the wrist, with the lap secured with a Kelly clamp



**Fig. 10.69** Posteroanterior sterile radiograph taken intraoperatively, prior to closure

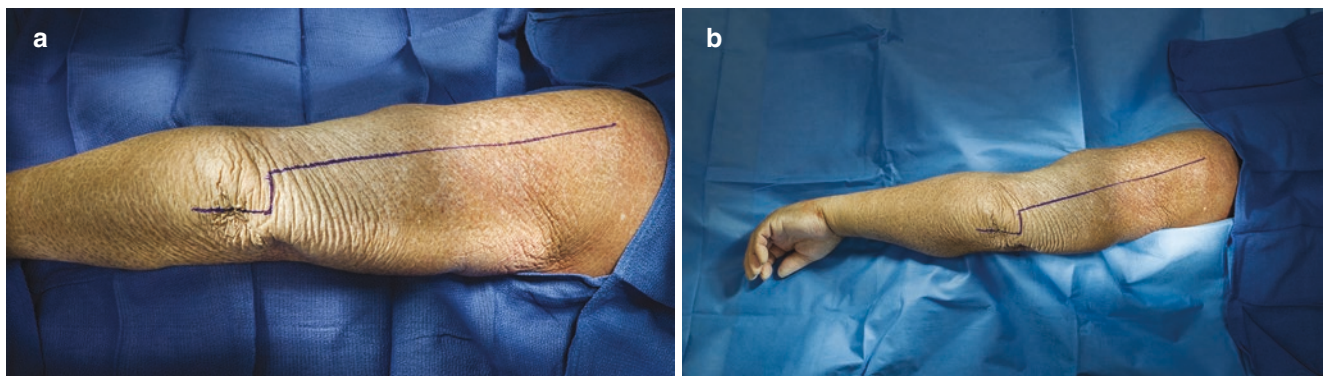




**Fig. 10.70** An axillary lateral, sterile drape is placed over the patient so the machine can get in the proper position; the drape is then discarded prior to reapproaching the field

The incision is to the radial side of the olecranon process; this is basically a posterolateral incision that follows along the lateral border of the humerus, then crosses at the tip of the olecranon laterally to medially, and then distally and medially, if needed, as for a supracondylar fracture. This route allows the incision to follow the course of the ulnar nerve and not to go straight across the olecranon process (Fig. 10.71). I feel that incising straight across the olecranon

process could be problematic because of skin tensioning. I have seen patients require flaps for coverage consequent to wound or incision dehiscence in this area because of the tension placed on the incision with flexion of the elbow. The incision is carried out with the tourniquet inflated. The flaps are elevated over the olecranon process. Commonly, a bursa is excised.



**Fig. 10.71** (a) Skin incision for posterior approach to the humerus of the left arm. (b) The proximal portion of the incision is along the lateral border of humerus, then across the olecranon process transversely, then

medial and distal from the medial tip of the olecranon. The incision is usually drawn after the tourniquet has been applied (not used here for demonstration purposes)



With the skin incision completed, the fascia is divided over the triceps and the lateral approach is carried out. The intermuscular septum will be retracted radially and the triceps medially or ulnarly. Going distally—in an area I define as the bare area—is where the middle collateral artery will be on the posterior aspect of the lateral column. This vessel has also been called (erroneously) the medial collateral artery. Distally, the interval between the anconeus and the triceps is developed, acknowledging that there is a potential for denervation of the anconeus, because the innervation to the anconeus is the radial nerve branch to the medial head of the triceps [21]. It is important to see the capsule reflection, if not the radial head itself, if you are dealing with a supracondylar fracture. The triceps elevation continues proximally, with the posterior radial collateral system being maintained in the base of the intermuscular septum (Figs. 10.72, 10.73, 10.74, 10.75, 10.76, 10.77, 10.78, and 10.79).



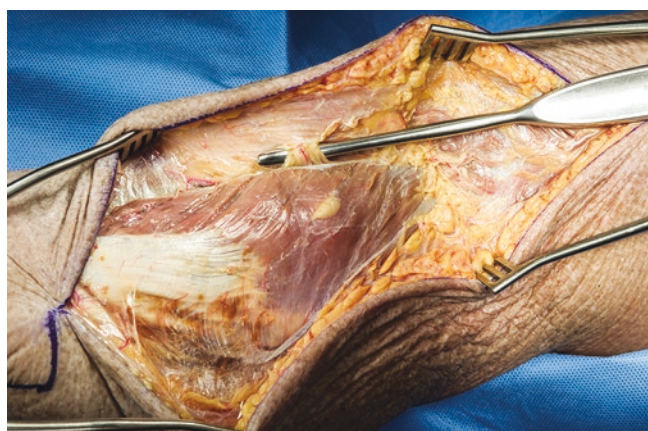
**Fig. 10.72** Joker deep to triceps fascia to be divided



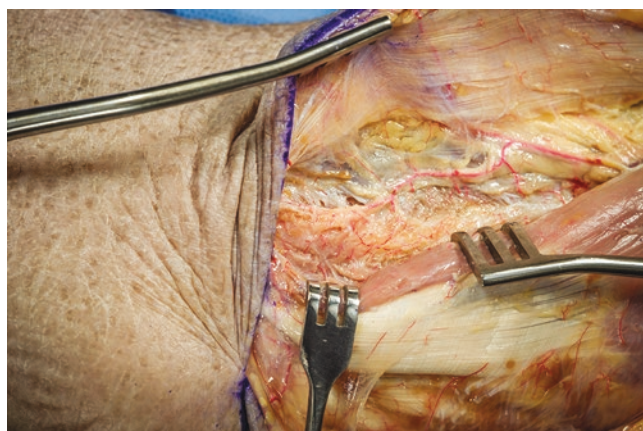
**Fig. 10.73** Fascia released, triceps exposed



**Fig. 10.74** Posterior radial collateral artery (*arrow*) exposed at base of the intermuscular septum

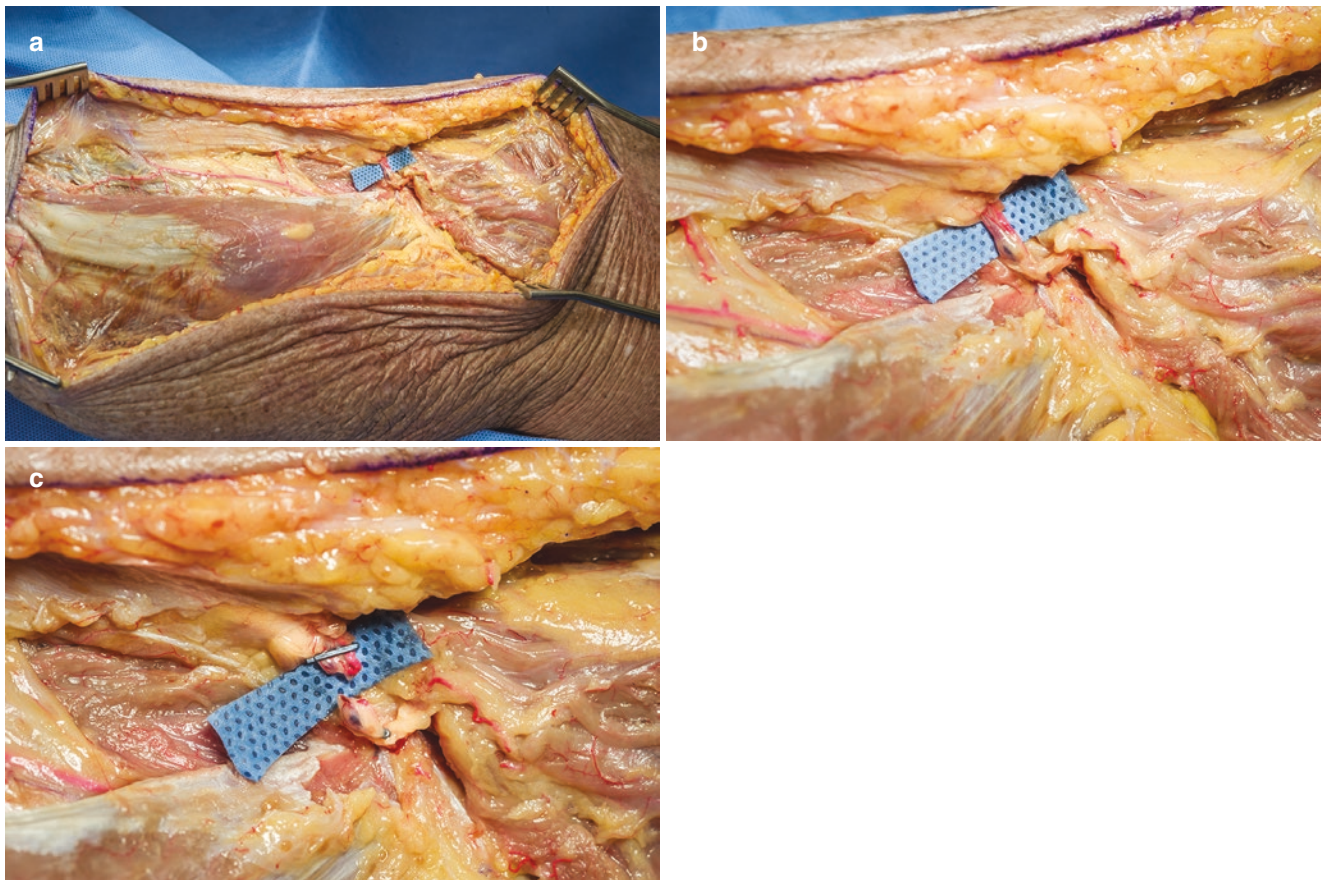


**Fig. 10.75** Perforator in the intermuscular septum off of the posterior radial collateral system

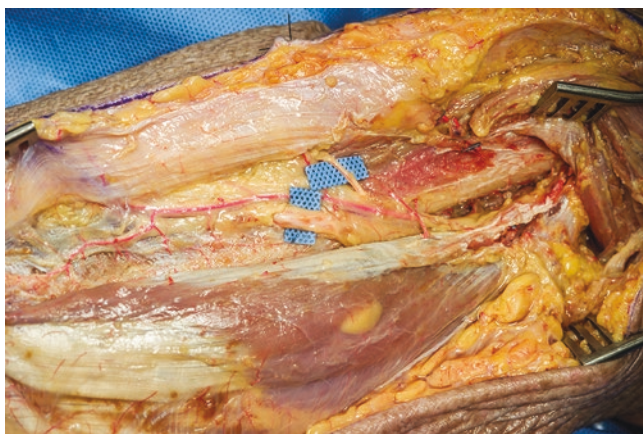


**Fig. 10.76** Middle collateral arterial plexus on the posterior aspect of the lateral condyle

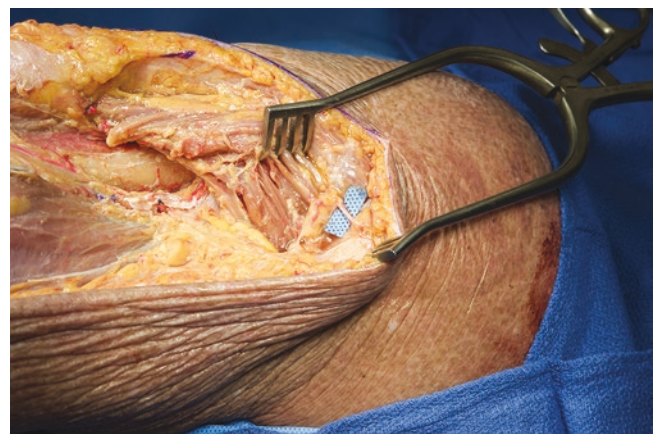




**Fig. 10.77** (a) Artery and vena comitantes at deltoid insertion. (b) Vessels prior to division. (c), Clips applied and vessels divided. Control these vessels first, as they love to retract and bleed



**Fig. 10.78** Blue backgrounds behind larger radial nerve and smaller brachio-cutaneous branch



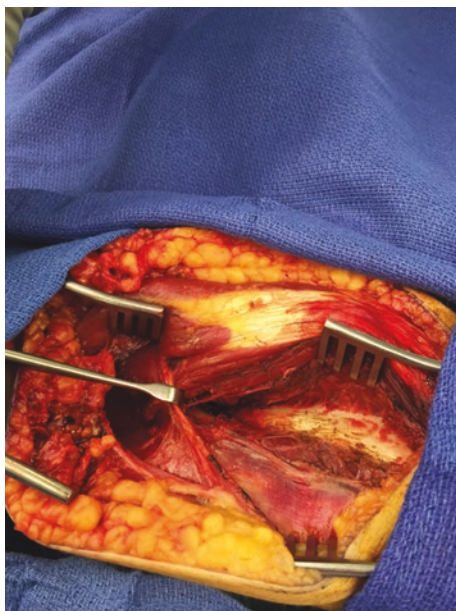
**Fig. 10.79** Cutaneous branches from the posterior branch of the axillary nerve, coursing between the deltoid insertion and the lateral head of the triceps



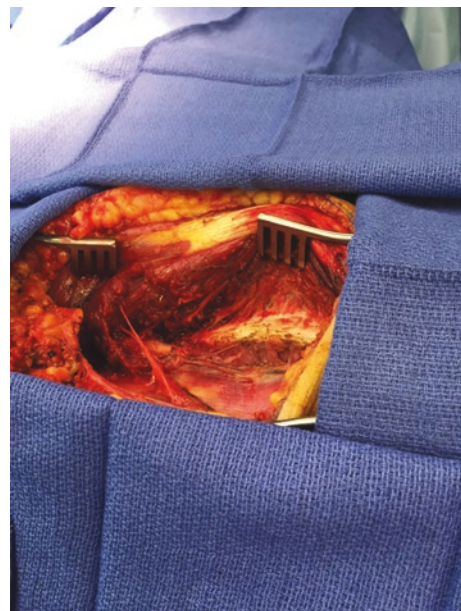
The proximal cutaneous nerves, along with the posterior cutaneous nerve of the forearm, are utilized as a guide back to the radial nerve, which courses around the lateral aspect of the humerus about 10 cm proximal to the lateral epicondyle [22]. It is common to see a brachio-cutaneous or antebrachio-

cutaneous nerve piercing the triceps, particularly in the distal third of the arm. I address this with intramuscular mobilization or, if only a small amount of triceps is involved, I will actually divide the triceps to let the nerve course back with the radial nerve itself (Figs. 10.80, 10.81, and 10.82).

**Fig. 10.80** Posterior approach to left humerus, with large brachio-cutaneous nerve piercing the triceps



**Fig. 10.81** Brachio-cutaneous nerve retracted, with radial nerve visualized deeper



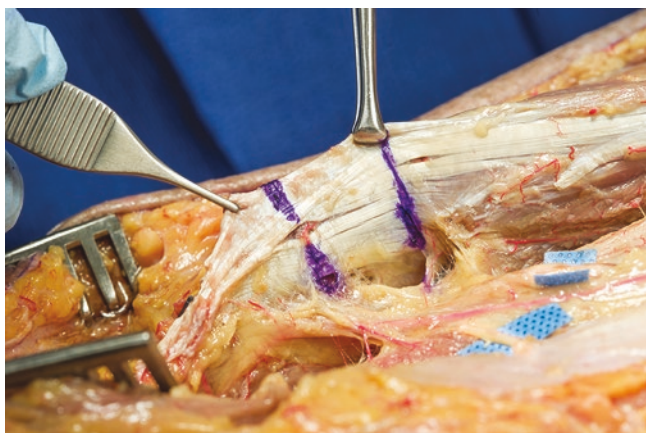
**Fig. 10.82** Portion of triceps divided to allow sensory nerve to drop next to the radial nerve, decreasing tension

Continuing proximally, the posterior radial collateral system merges into the profunda, allowing visualization and mobilization of the radial nerve. I do not dissect and separate the profunda, venae comitantes, and nerve, in order to minimize the stress applied to the individual structures in this neurovascular bundle. The dissection is carried as proximal as possible with the sterile tourniquet. Because of concern about telescoping, I generally prefer a pneumatic tourniquet and tend not to use the roll-up type, which allows more proximal dissection. The fracture, depending on its level (which unfortunately is often located where the radial nerve crosses posteriorly over the humerus), can now be visualized with elevation of the triceps, with no medial exposure required between the triceps and the ulnar nerve. Fracture preparation can be carried out and, commonly, provisional fixation can be performed. This allows tamponading of the bleeding from the humeral canal and minimizes the potential soft tissue stripping that would expose the radial nerve to lateral spikes.

Once the nerve (and, if possible, the fracture) is identified, the tourniquet is deflated, and the skin incision is carried more proximally, into an area that is palpable, an indent

between the deltoid and the lateral head of the triceps. The proximal bare area is defined by the deltoid and lateral head triceps juncture. Depending on the level of the proximal dissection, care must be taken, to avoid injury to the cutaneous branches coming off the posterior branch of the axillary nerve. This will help you to dissect down to the axillary nerve and to define the level of the proximal extent of plating. The lateral head of the triceps will be mobilized away from the intermuscular septum, allowing exposure of the radial nerve neurovascular bundle. The neurovascular bundle is then elevated with a Freer elevator to allow the plate to be placed deep to the nerve. In certain scenarios, I transpose the nerve anteriorly, particularly in fracture patterns that are concerning for delayed healing and where further surgery may be required, such as bone grafting or radial nerve repairs that would be facilitated with humeral shortening. In general, I prefer not to transpose the nerve through the fracture.

In an effort to minimize postoperative radial nerve palsies, I resect a portion of the fascia deep to the lateral head of the triceps over the nerve, so that the nerve will not be pinched by the deeper fascia (Figs. 10.83, 10.84, 10.85, and 10.86).



**Fig. 10.83** Excision of a portion of the deep fascia off the lateral head of the triceps to decrease pressure or scissoring on the radial nerve when the plate is slid deep to the nerve



**Fig. 10.84** Incisions in fascia



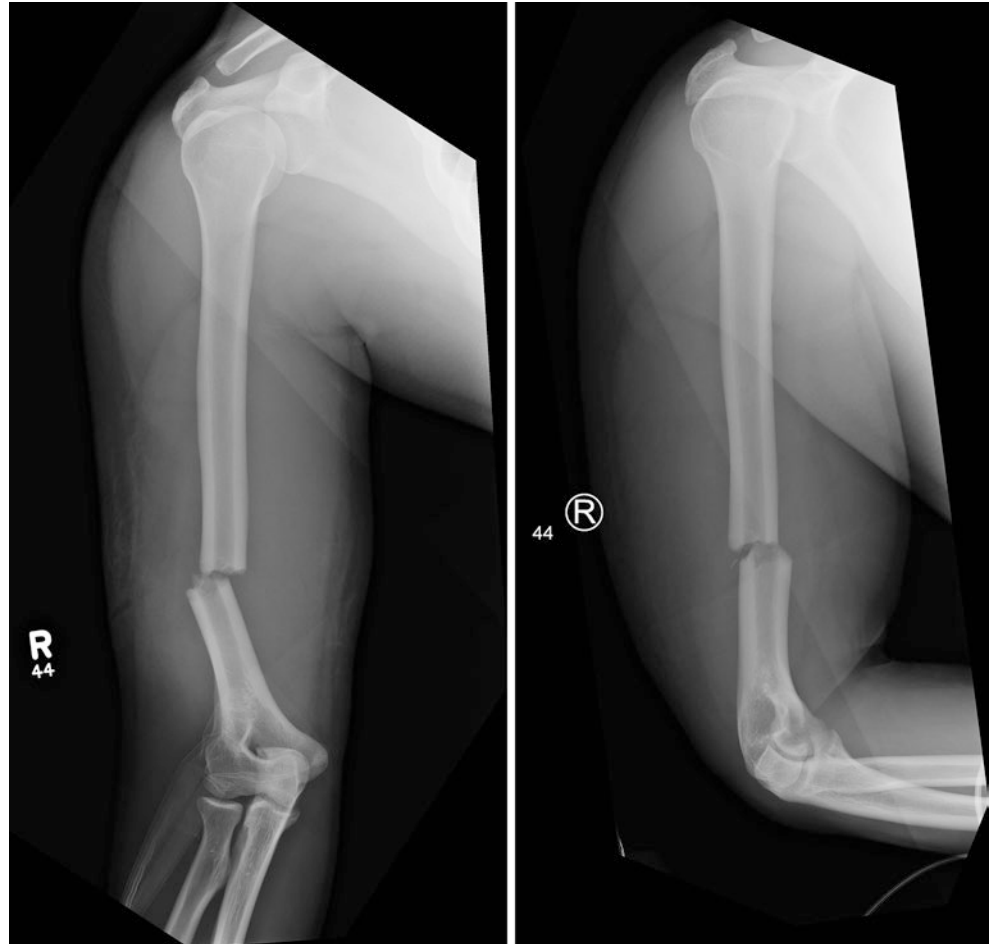
**Fig. 10.85** Partial excision of fascia



**Fig. 10.86** Excision completed

If the fracture has not been previously provisionally reduced and stabilized, the fracture is prepared and reduction is performed. Provisional fixation with mini-fixation is performed, followed by definitive plate fixation. As previously

noted, I prefer to use 3.5-mm plates. Even with the 3.5-mm plates, I let the patient bear weight, depending on the level of fracture and the construct obtained (Figs. 10.87 and 10.88).



**Fig. 10.87** Injury radiographs of low left distal humeral shaft fracture

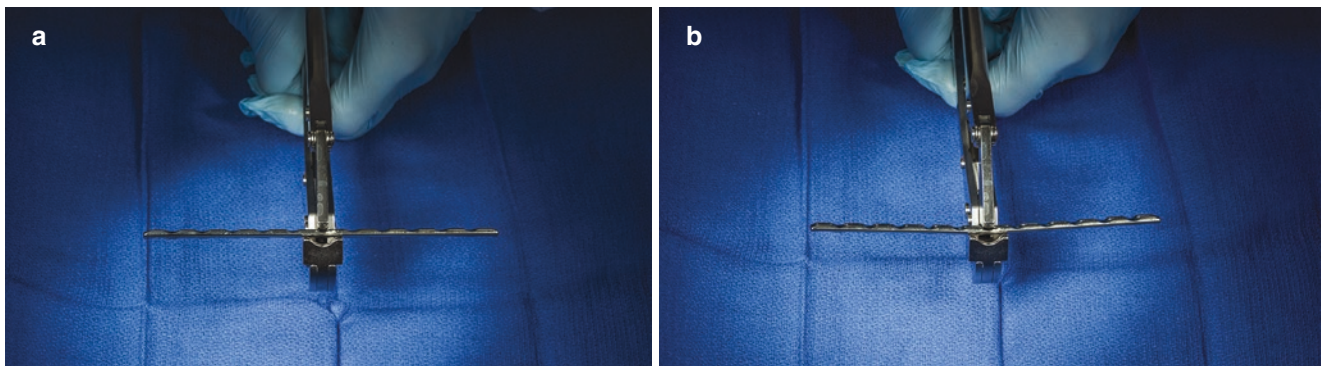


**Fig. 10.88** Fixation with a distal humeral locking plate to allow weight bearing, which was curtailed when the plate started to bend. The fracture healed without revision

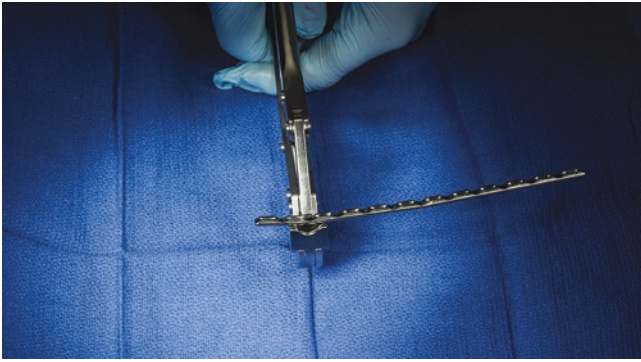


I prefer four screws over a five-hole spread to improve the working length of the plate. In larger individuals, I use a 4.5-mm narrow plate (Figs. 10.89, 10.90, 10.91, 10.92, 10.93, 10.94, 10.95, 10.96, 10.97, 10.98, 10.99, 10.100, 10.101,

10.102, 10.103, 10.104, 10.105, 10.106, 10.107, 10.108, 10.109, 10.110, 10.111, 10.112, 10.113, 10.114, 10.115, 10.116, 10.117, 10.118, 10.119, 10.120, 10.121, and 10.122).



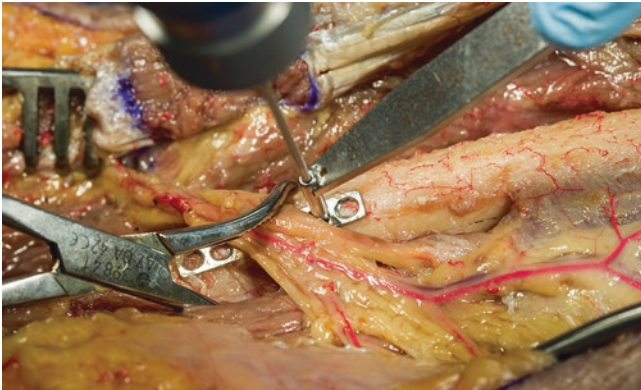
**Fig. 10.89** (a) Pre-stressing 3.5-mm limited-contact dynamic compression plate (LC-DCP) with acute bend. (b) Bend completed



**Fig. 10.90** Distal bend incorporated to contour to anterior flare of distal humerus



**Fig. 10.91** Simulated fracture just distal to the radial nerve, viewed from the medial side



**Fig. 10.92** Provisional fixation of humerus following reduction with tenaculum and 2.0-mm DCP mini-fragment plate



**Fig. 10.93** First screw inserted eccentric in plate



**Fig. 10.94** Second screw inserted in loaded fashion

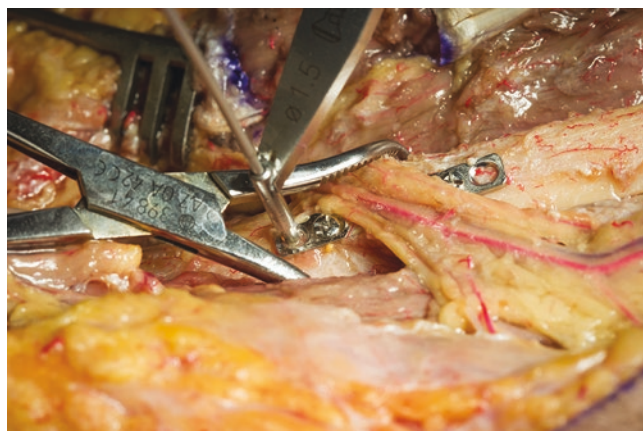


**Fig. 10.95** Screw insertion





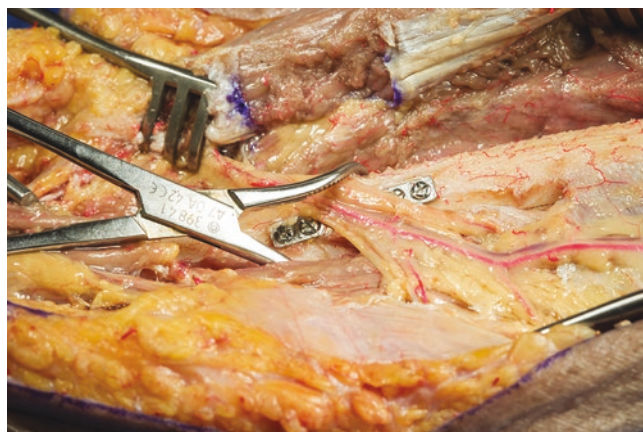
**Fig. 10.96** Initial fixation complete, with compression applied



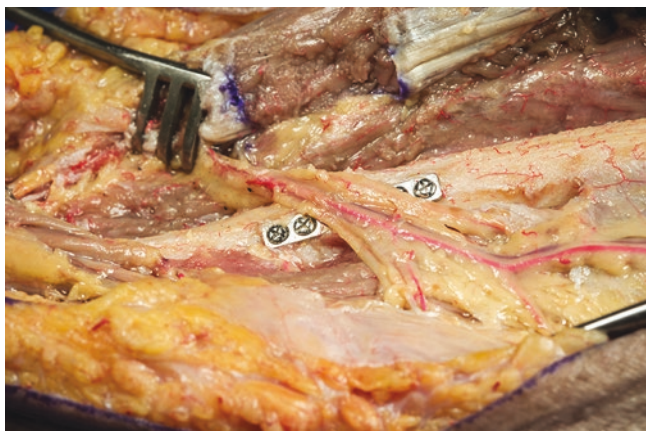
**Fig. 10.97** Fixation completed with outboard screws



**Fig. 10.98** Holes drilled, still with a little compression so as not to inadvertently drill in distraction



**Fig. 10.99** Screws inserted

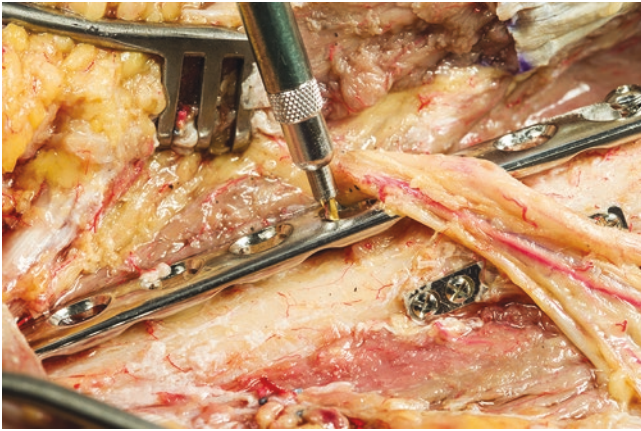


**Fig. 10.100** Tenaculum removed



**Fig. 10.101** Fixation with 3.5-mm plate; the first hole is drilled in the distal segment to ensure proper position relative to the olecranon fossa

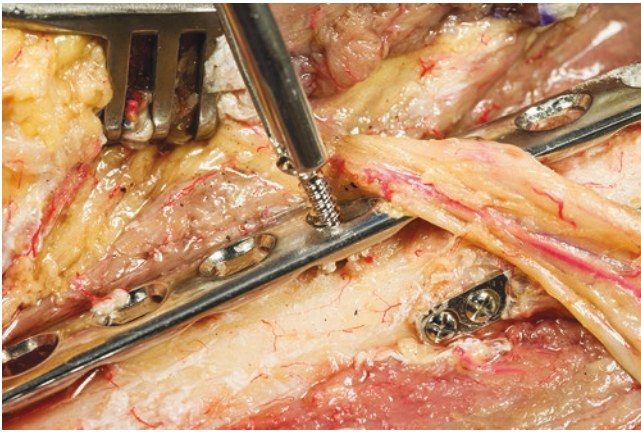




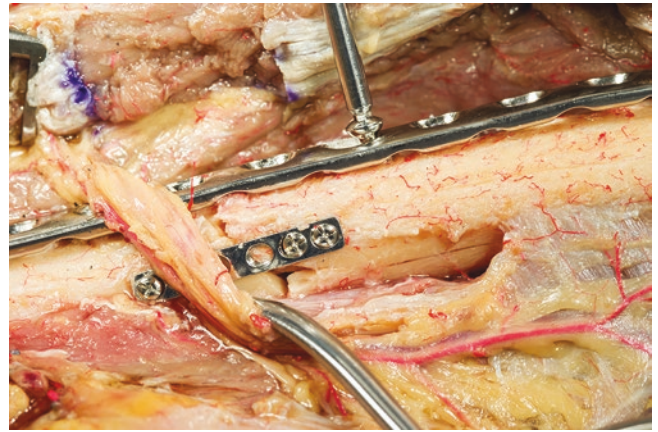
**Fig. 10.102** Proximal hole drilled in compression; note the distal screw engaging the plate but not completely seated, to give compression from both sides of the fixation



**Fig. 10.103** Eccentric hole drilling



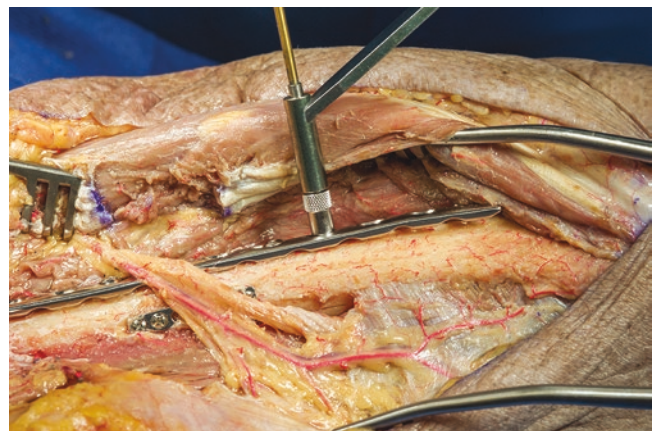
**Fig. 10.104** Screw insertion



**Fig. 10.105** Sequential screw tightening. Go back and forth when tightening. Do not take one screw all the way home, because that may lock out the other screw from sliding down the hole for compression

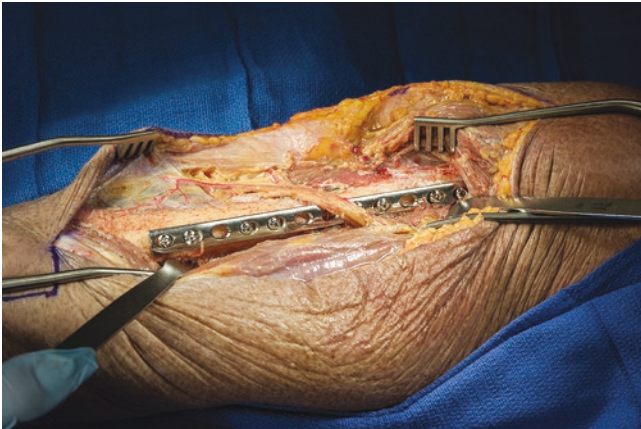


**Fig. 10.106** Final screw seating. Compression can still be applied with the mini-fragment plate in place



**Fig. 10.107** Remaining screws inserted in loaded (not necessarily compression) mode





**Fig. 10.108** Fixation with four screws over holes



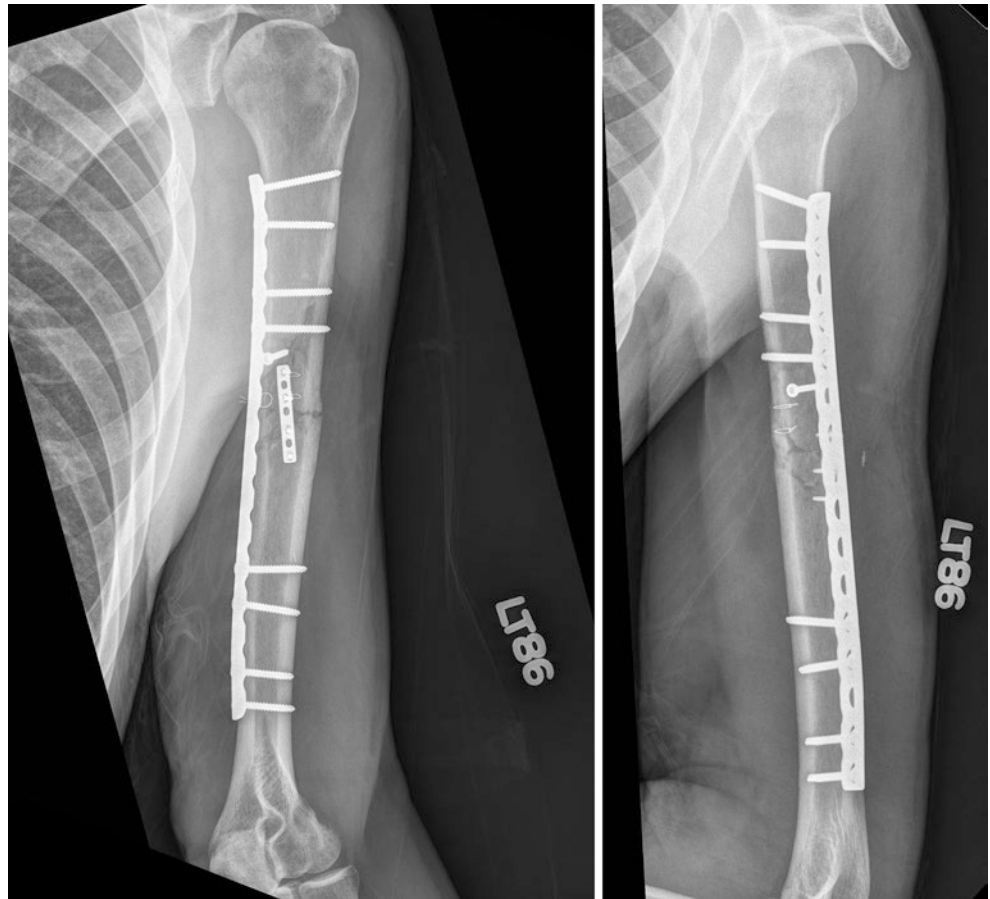
**Fig. 10.109** Do not put Penroses around nerves



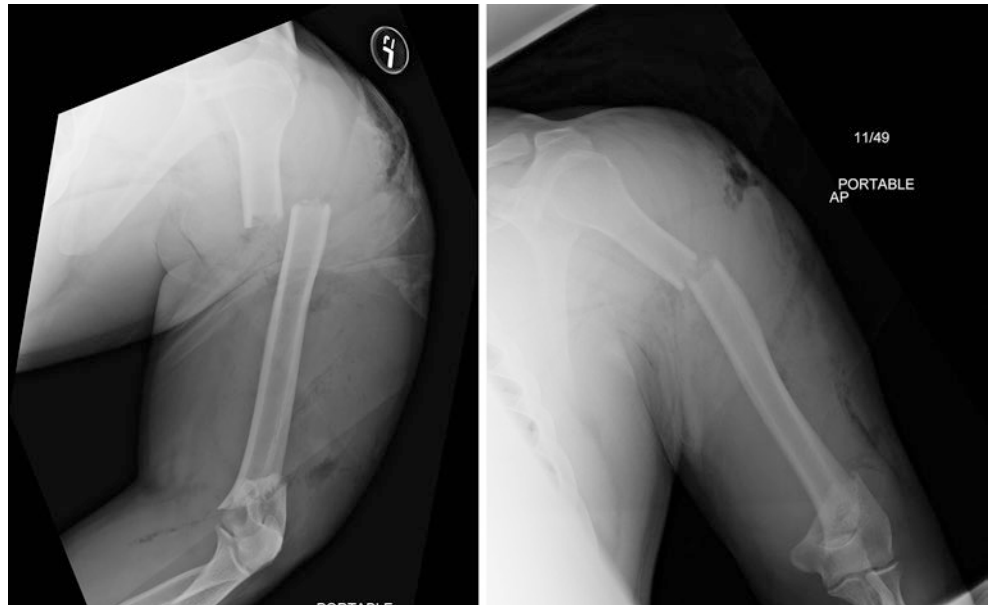
**Fig. 10.110** Injury radiographs of left humeral shaft fracture



**Fig. 10.111** Radiographs following open reduction with internal fixation (ORIF) through posterior approach with the sequence of insert two screws, then skip a hole, and the insert two screws

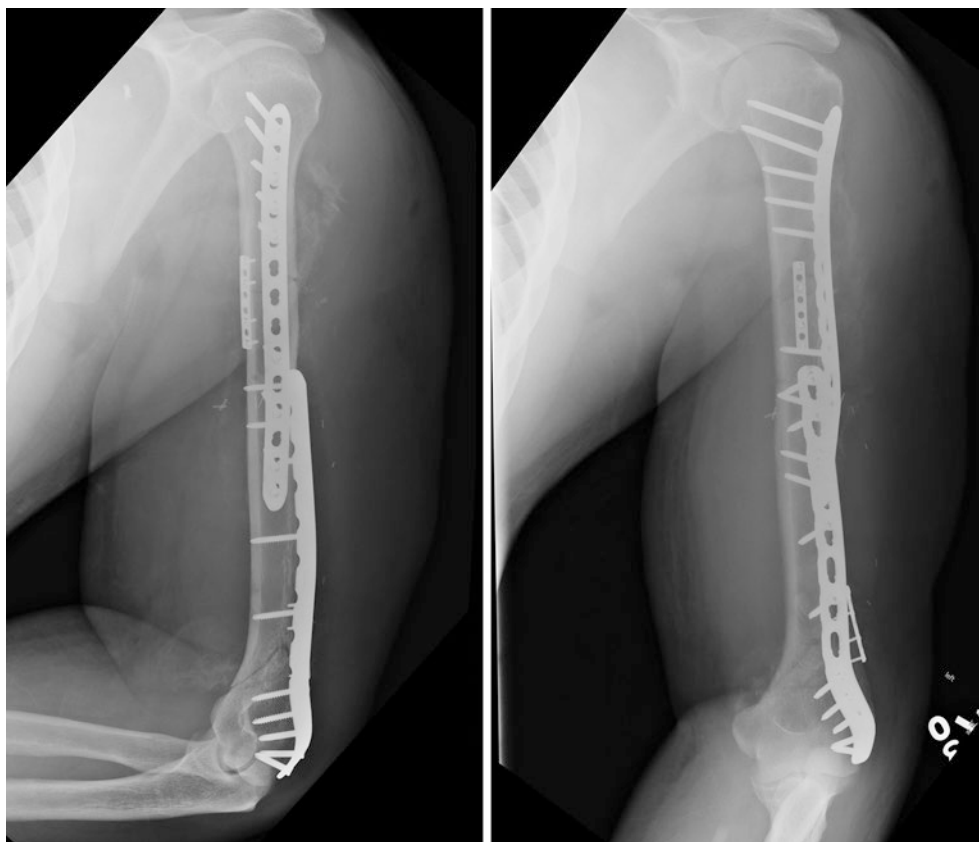


**Fig. 10.112** Injury radiographs of open, segmented left humeral shaft fracture

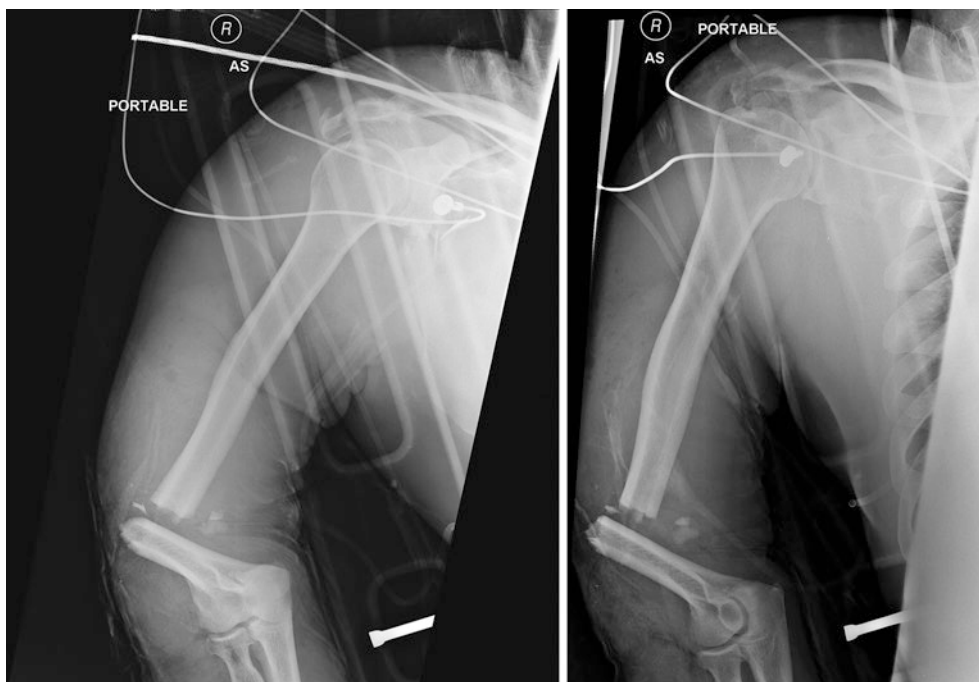


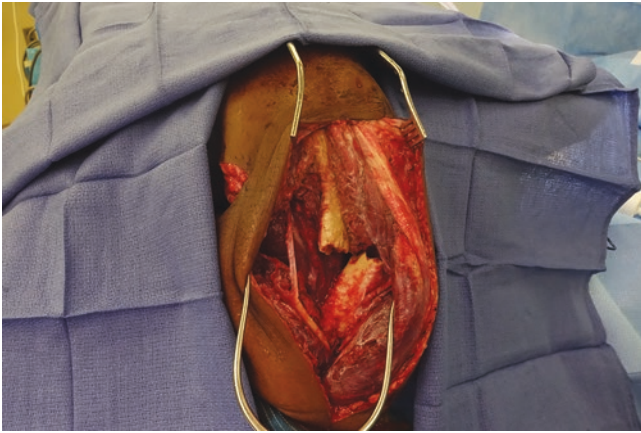


**Fig. 10.113** Radiographs following ORIF via two incisions, anterolateral and posterior

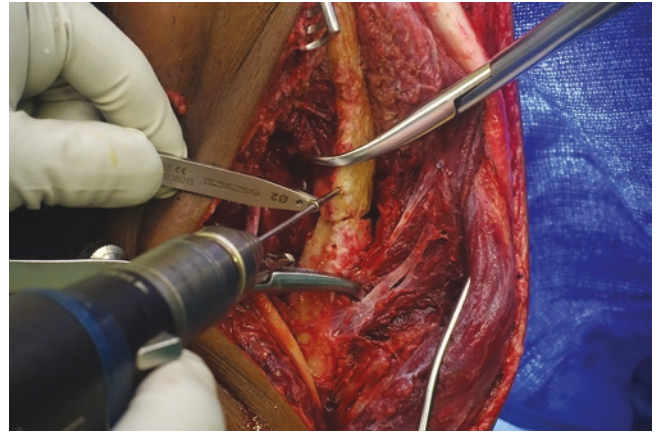


**Fig. 10.114** Injury radiographs of open right humeral shaft fracture in a patient with associated closed head injury and C-spine injury, necessitating surgical intervention with the patient supine with the arm across his chest on a Mayo stand for a posterior approach

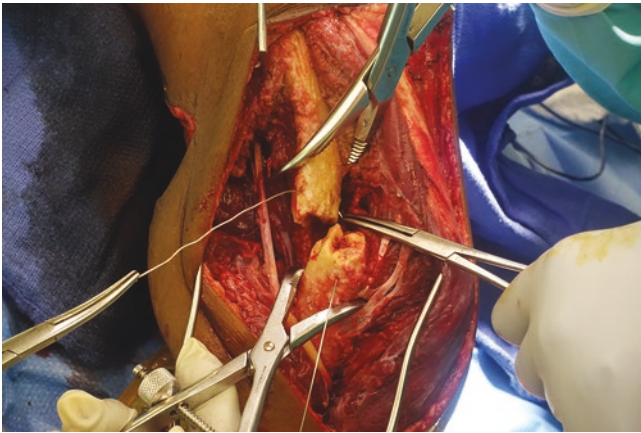




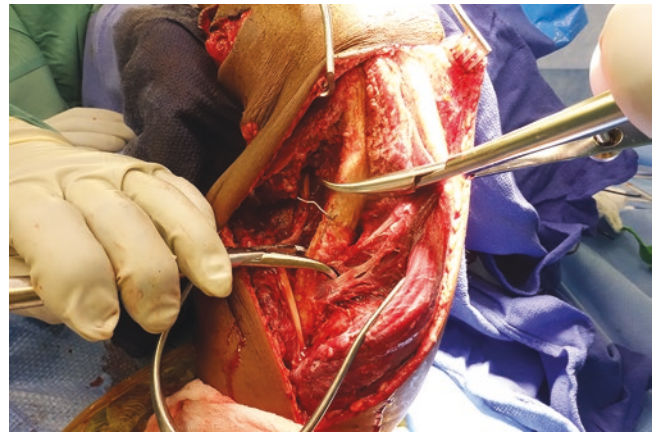
**Fig. 10.115** Fracture exposed and prepared for reduction and provisional fixation



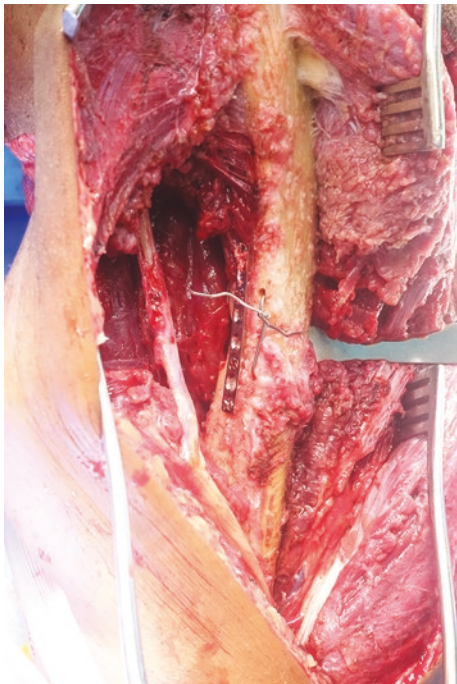
**Fig. 10.116** Two transverse holes drilled with a 2.0-mm drill bit in preparation for passage of a 20-gauge wire. This technique is not used in every case, but is a trick to use when the fragments are “floating” and difficult to control



**Fig. 10.117** 20-gauge wire being passed

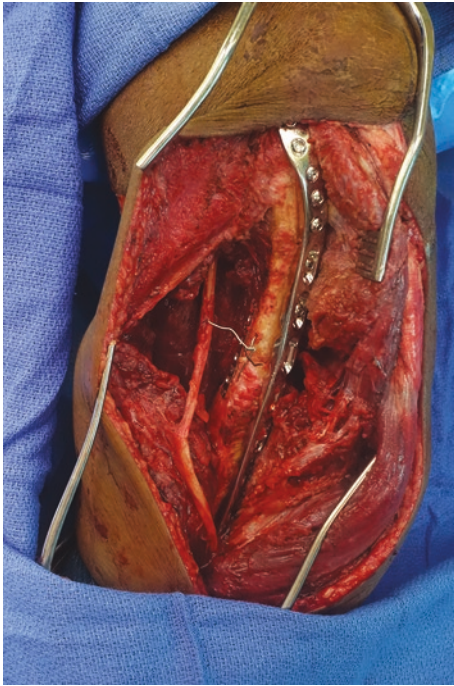


**Fig. 10.118** Wire tightened

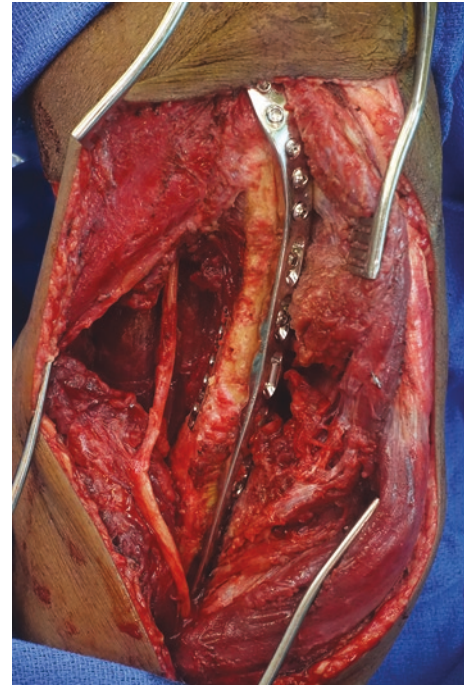


**Fig. 10.119** 2.0-mm mini-fragment plate applied anterolaterally

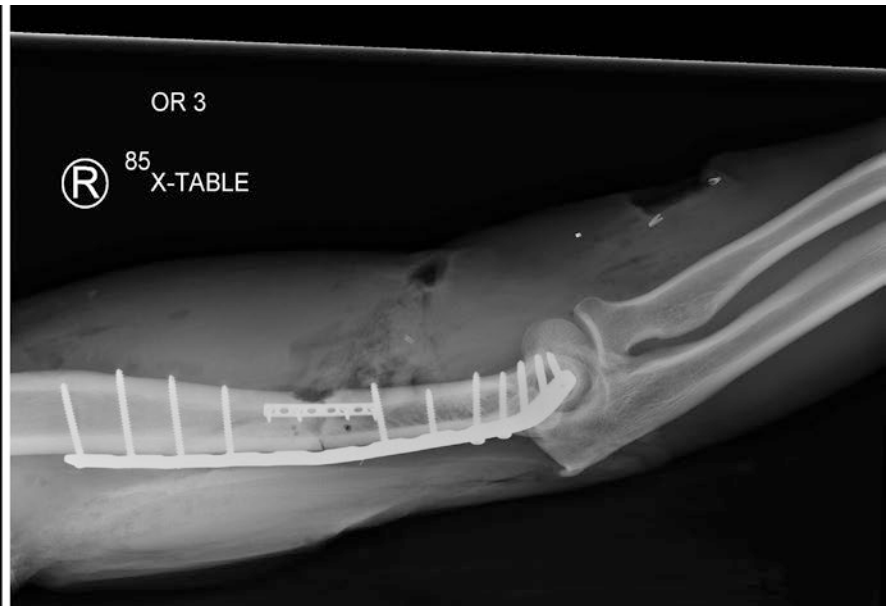




**Fig. 10.120** Definitive plating with an extra-articular supracondylar plate to add a little “beef” and length to the fixation, to allow the arm to be used for monitoring and to try to obviate the fracture



**Fig. 10.121** Final fixation with 20-gauge wire removed



**Fig. 10.122** Intraoperative radiographs



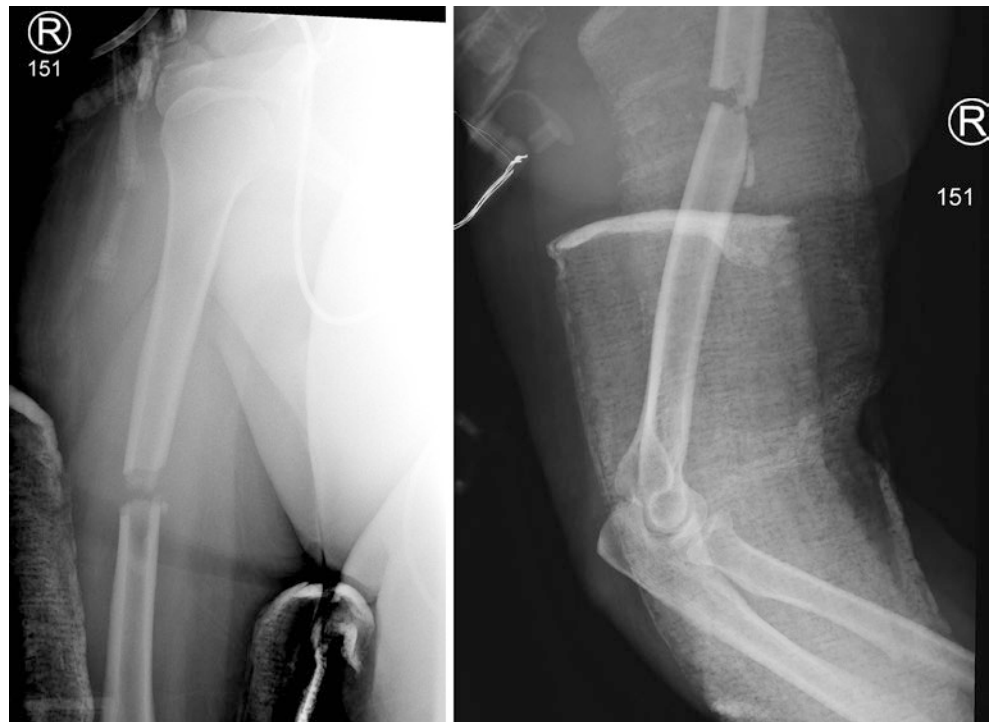
### 10.3.2 Intramedullary Nailing

IM nailing is performed in similar fashion to proximal humeral nailing, with the caveat that the distal locks can cause concern regarding potential radial nerve injury. To avoid nerve injury, I make a generous lateral incision and put baby Bennett or Hohmann retractors around the humerus, in order to directly see it. I also use a posterior-to-anterior screw for the distal lock, not an anterior-to-posterior screw, because of my concern not to injure the median nerve via the anterior approach. Sometimes I do not use distal locking screws because of concerns over situations that could cause a torque

to the arm, creating a supracondylar fracture at the distal locking screw site, such as may happen when paraplegics use the arms for transfer. Finally, the potential distal extent of the nail may be deceiving, as the AP radiograph might have you believe that the nail could stop just above the olecranon fossa. On the lateral view, however, the anterior curve of the humerus can be appreciated, reflecting the difficulty with a straight nail hitting the posterior cortex, thus limiting the length of the nail that can be used (Figs. 10.123, 10.124, and 10.125).



**Fig. 10.123** Single injury radiograph of right humeral shaft fracture



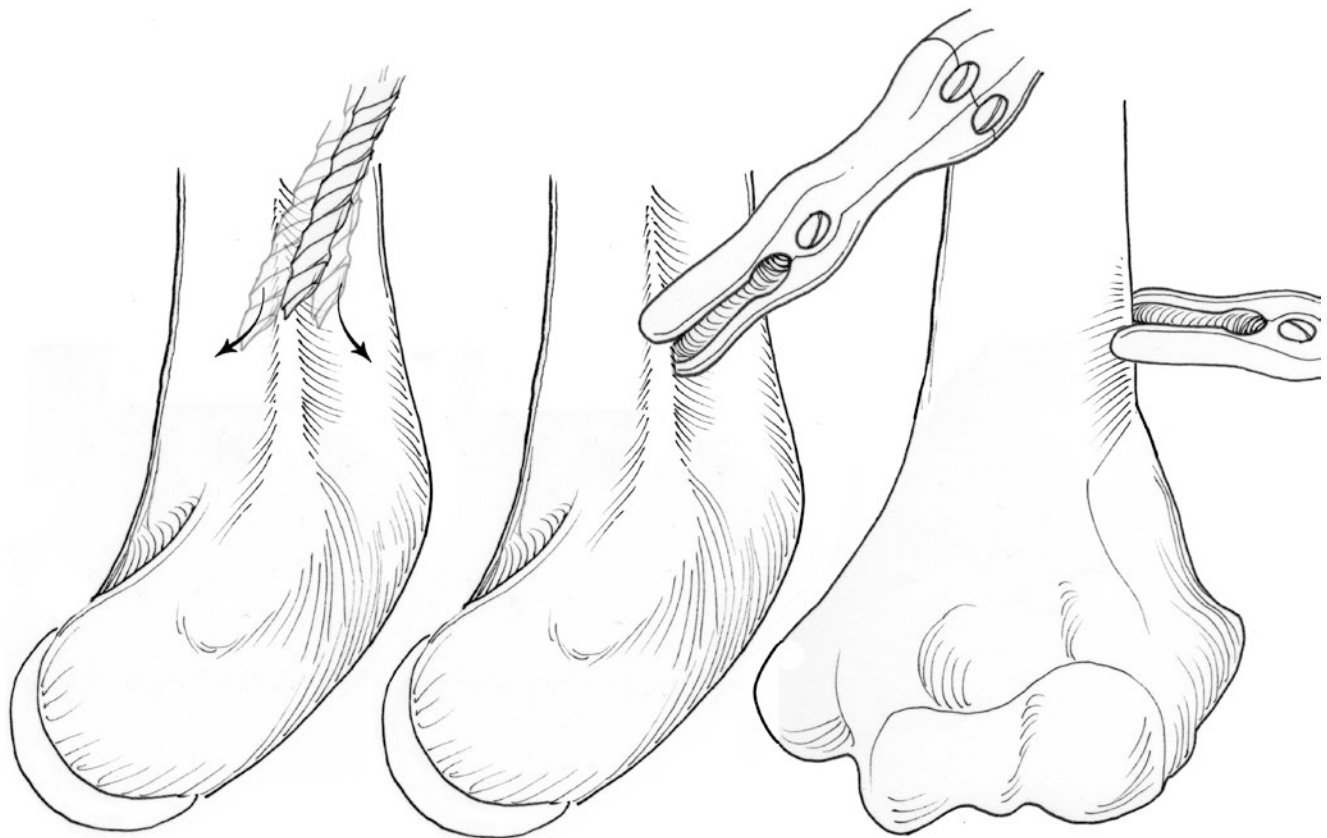
**Fig. 10.124** Splinting radiographs. Note patient habitus



**Fig. 10.125** Intramedullary fixation without distal locks. Note how the distal end of the nail engages the distal posterior cortex

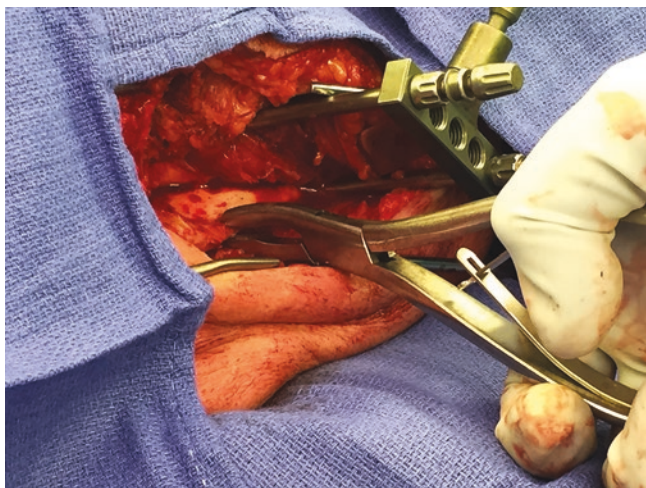
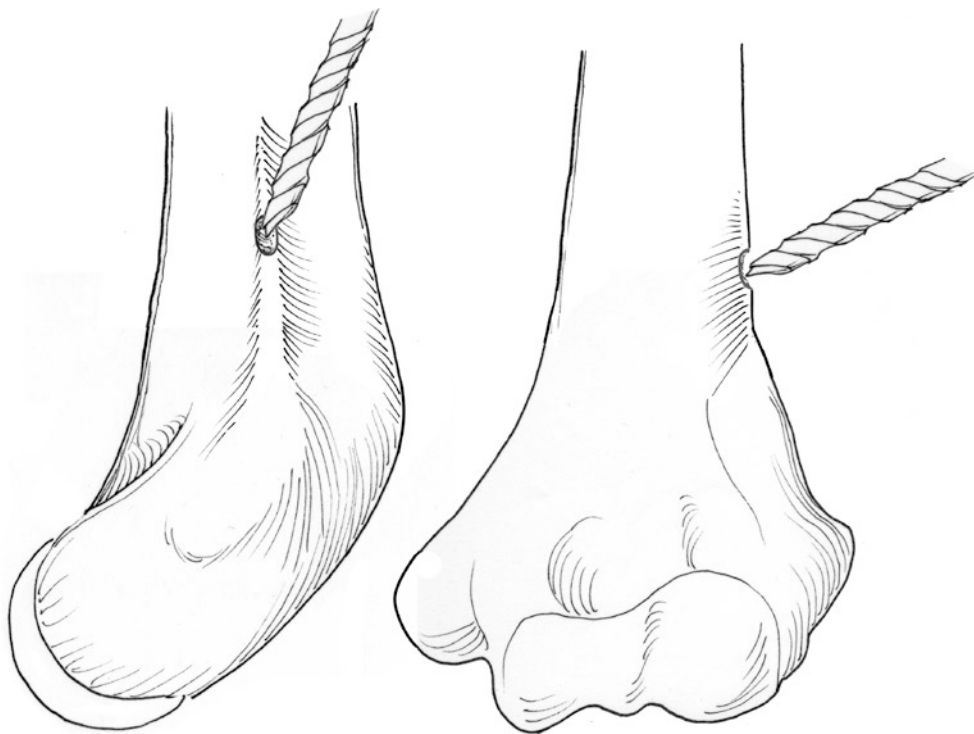
### 10.3.3 External Fixation

When applying an external fixator for humeral fractures, I use a four-pin construct with two 4-mm half-pins placed just at the inferior neck level in an anterolateral placement in a 1–4 spread and the distal two in a 1–5 spread. Distally, one pin goes above and one below the olecranon fossa. The more proximal half pin in the distal group can be difficult to insert, and a helpful hint is to nibble off a little of the ridge with a rongeur first, and then drill (Figs. 10.126, 10.127, 10.128, 10.129, 10.130, and 10.131).

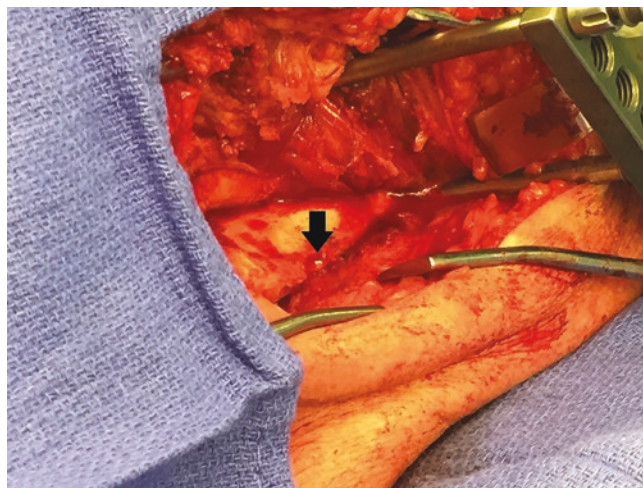


**Fig. 10.126** Nibbling off a portion of the supracondylar ridge to prevent drill bit slippage

**Fig. 10.127** Drilling the hole is now easier, with the drill point sitting in a little crater

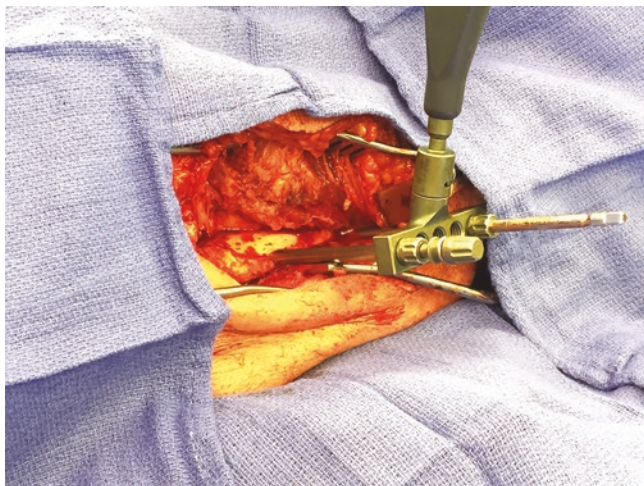


**Fig. 10.128** Clinical example of ridge preparation

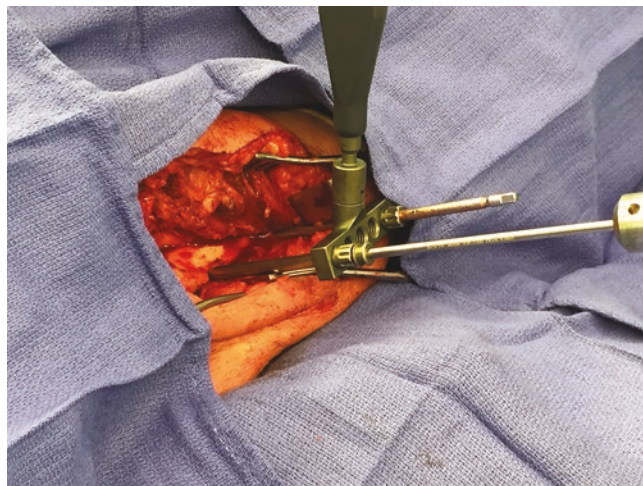


**Fig. 10.129** Crater created (arrow)





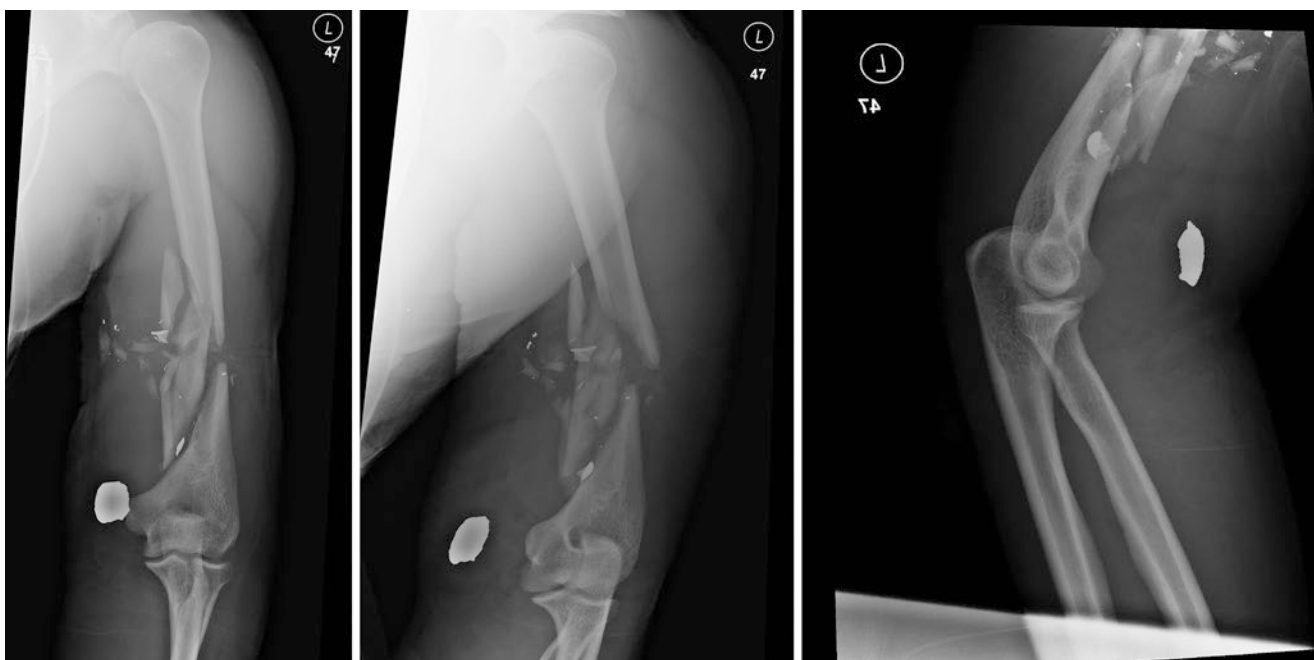
**Fig. 10.130** Hole drilling through jig



**Fig. 10.131** Completion of hole drilling prior to half-pin insertion

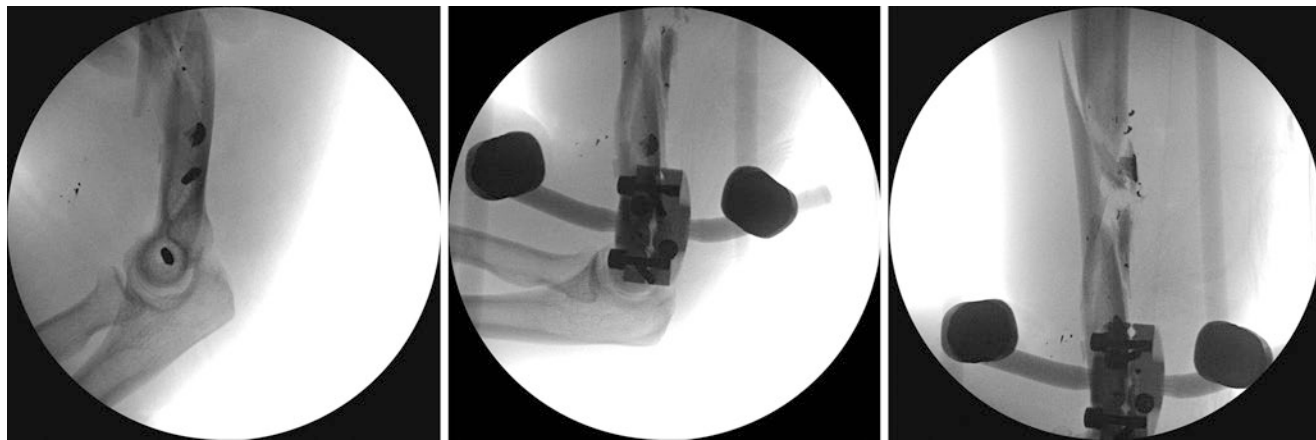
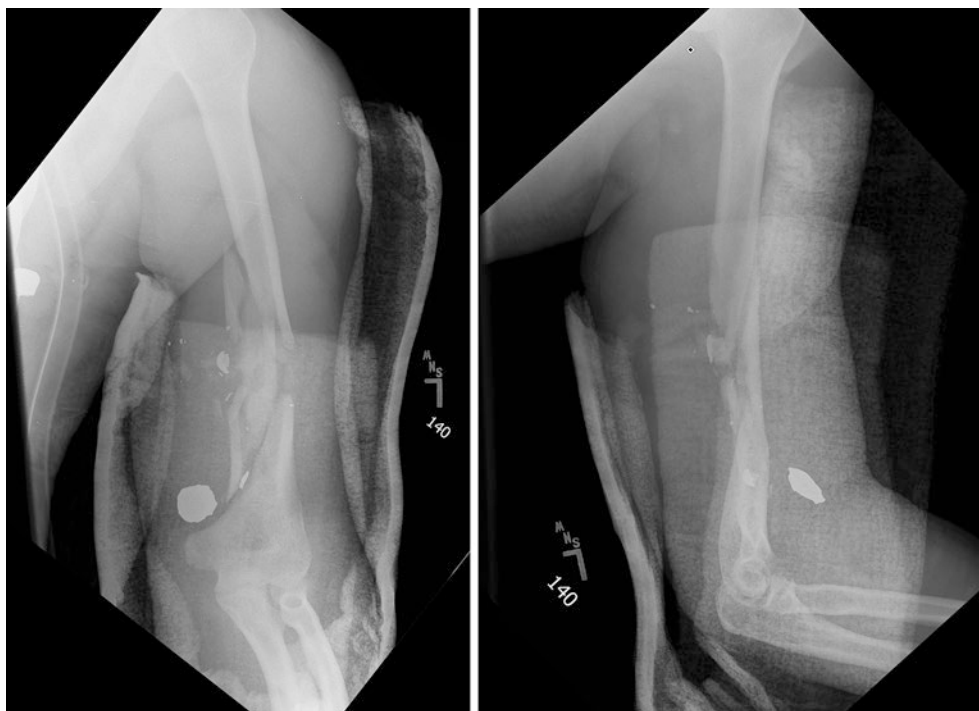
The more distal pin is usually inserted first at the epicondyle level, using the concentric circle technique for

insertion (Figs. 10.132, 10.133, 10.134, 10.135, 10.136, and 10.137).

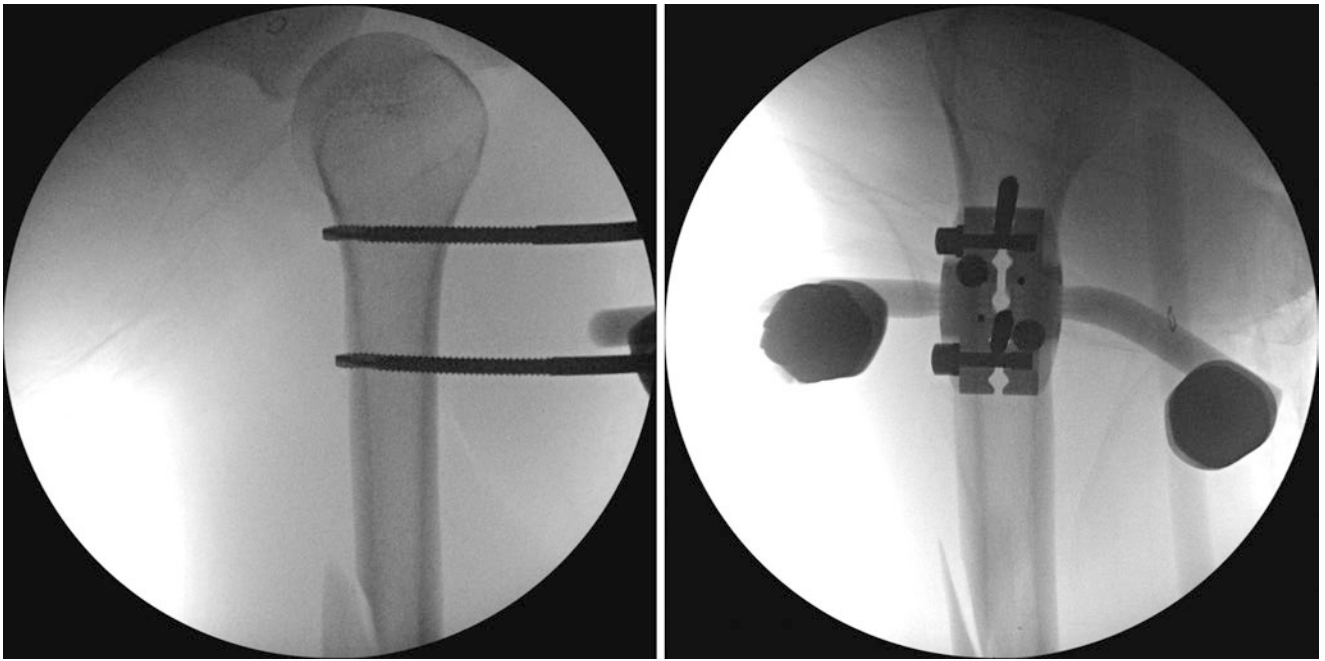


**Fig. 10.132** Injury radiographs of left humeral fracture secondary to metallic foreign body

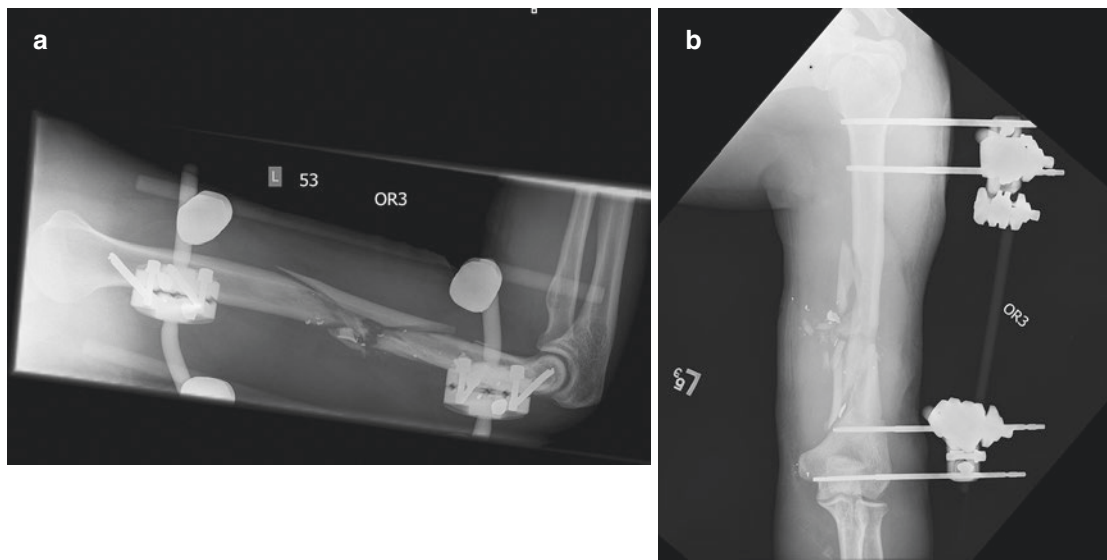
**Fig. 10.133** Splint radiographs. An external fixator was applied to expedite care because more than one metallic foreign body was present



**Fig. 10.134** Pin insertion, frame construction, and reduction



**Fig. 10.135** Proximal pin insertion



**Fig. 10.136** (a) Reduction in external fixator, axillary lateral view. (b) Reduction in external fixator, anteroposterior view



**Fig. 10.137** Final radiographs at time of discharge



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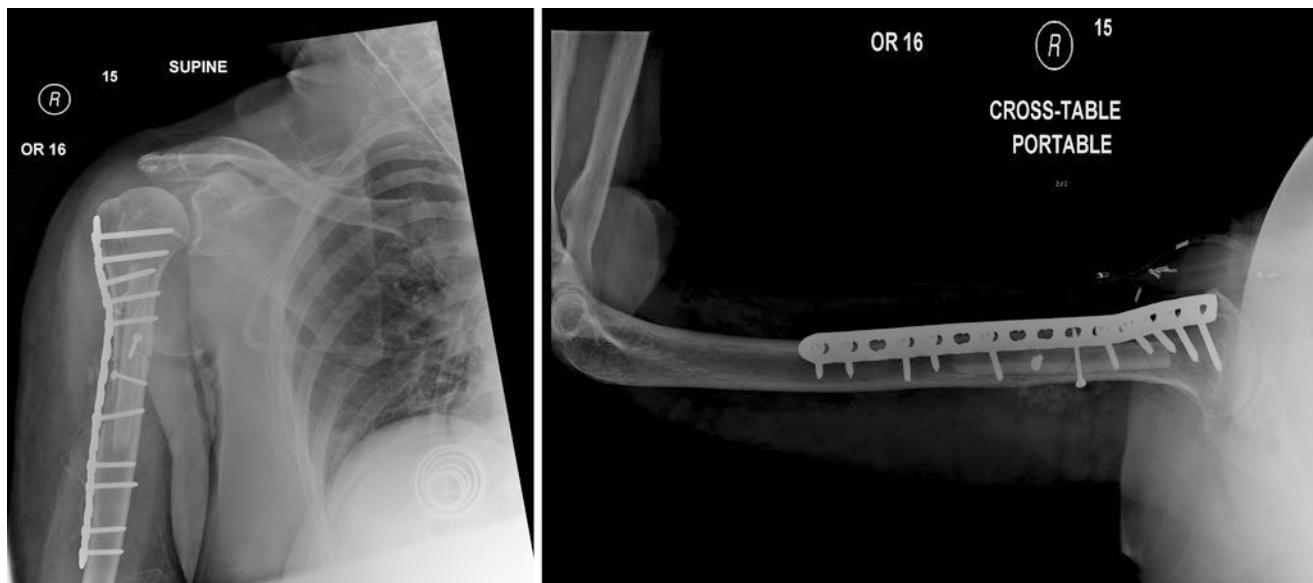
## 11.1 Choosing an Approach to Humeral Nonunion

The focus and spirit of this book is directed at acute fracture care. The intramedullary (IM) fibula technique to be discussed in this chapter regarding humeral nonunion can occasionally also be incorporated in the acute scenario, however (Figs. 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, and 11.7).



**Fig. 11.1** Radiographs of proximal right humeral shaft fracture in fracture brace. The patient was referred for open reduction and internal fixation (ORIF) after opting for surgery





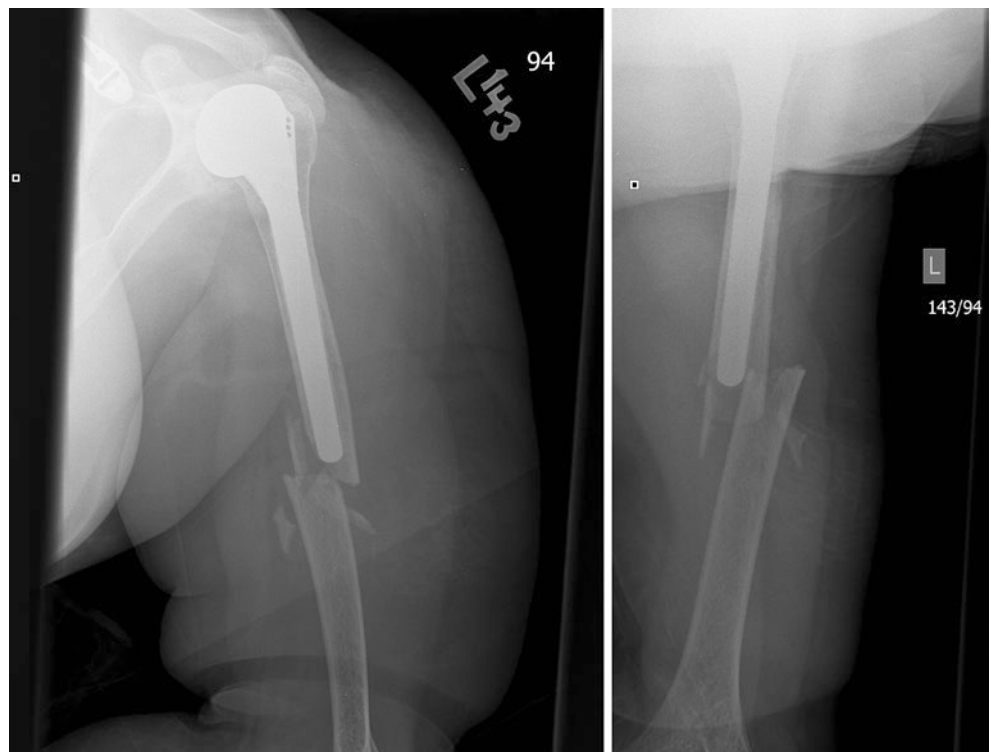
**Fig. 11.2** Intraoperative radiographs following ORIF, with intramedullary fibula augmentation because of concern over bone quality found intraoperatively. Note top of plate cut



**Fig. 11.3** Two-year follow-up radiographs of healed right humeral fracture with no limitations in activity



**Fig. 11.4** Follow-up shoulder radiographs on discharge

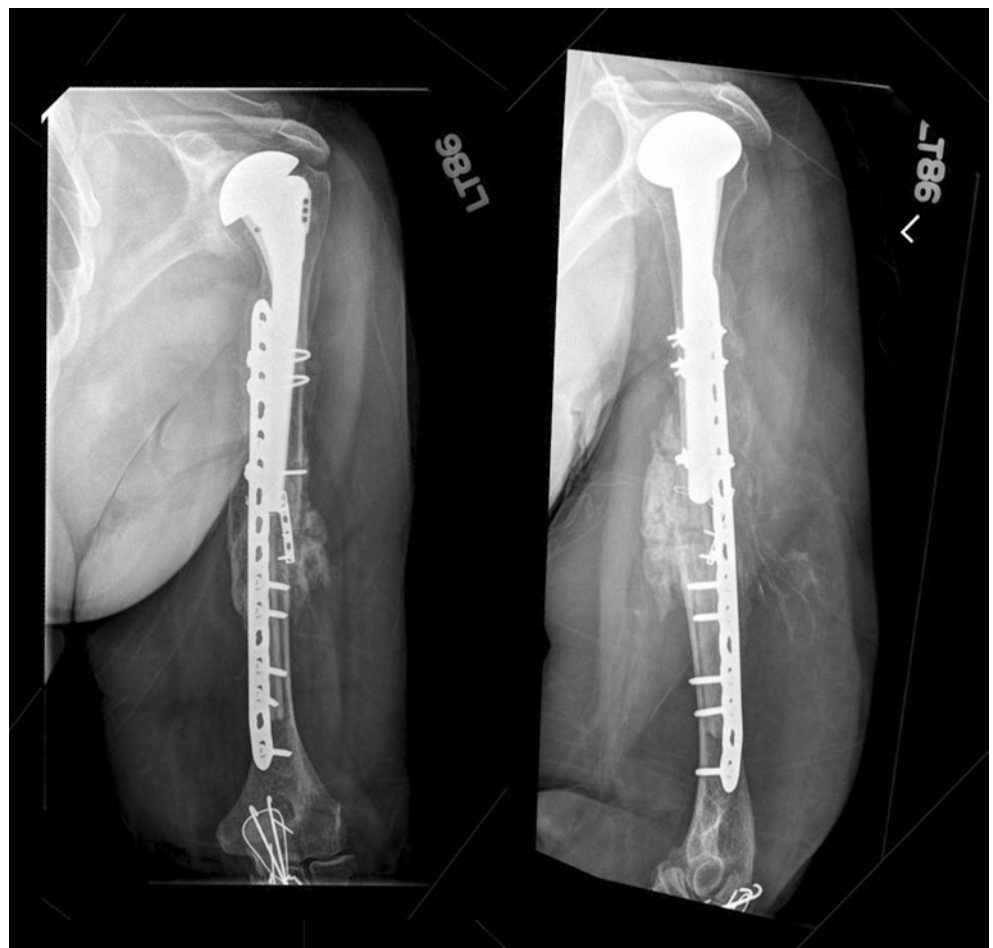


**Fig. 11.5** Injury radiographs of left humeral periprosthetic fracture and olecranon fracture

**Fig. 11.6** Radiographs following ORIF with the distal shaft augmented with intramedullary fibula



**Fig. 11.7** Radiographs on discharge, with abundant callus noted





The incidence of humeral nonunion is not insignificant, with 2–20% of cases reported as having “healing problems” [1–3]. In patients with better bone quality, I favor ORIF of humeral shaft nonunion rather than an IM nail [4–8]. After discussion with the patient, I use either cancellous allograft with a bone morphogenetic protein (BMP) product such as Infuse® (Medtronic), acknowledging label recommendations, or I use an autologous cancellous bone graft. Either fares well, but most patients favor the allograft.

Humeral shaft nonunion in elderly patients can be problematic. For many years, I have been using an IM fibula technique with compression plating when the bone quality is poor, particularly in atrophic nonunions [9–12]. In the diaphyseal fracture, the fibula can be inserted at the fracture using either an antegrade or retrograde placement. With proximal nonunions, I sometimes go through the rotator cuff, as if performing an IM nailing.

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## 11.2 Surgical Technique

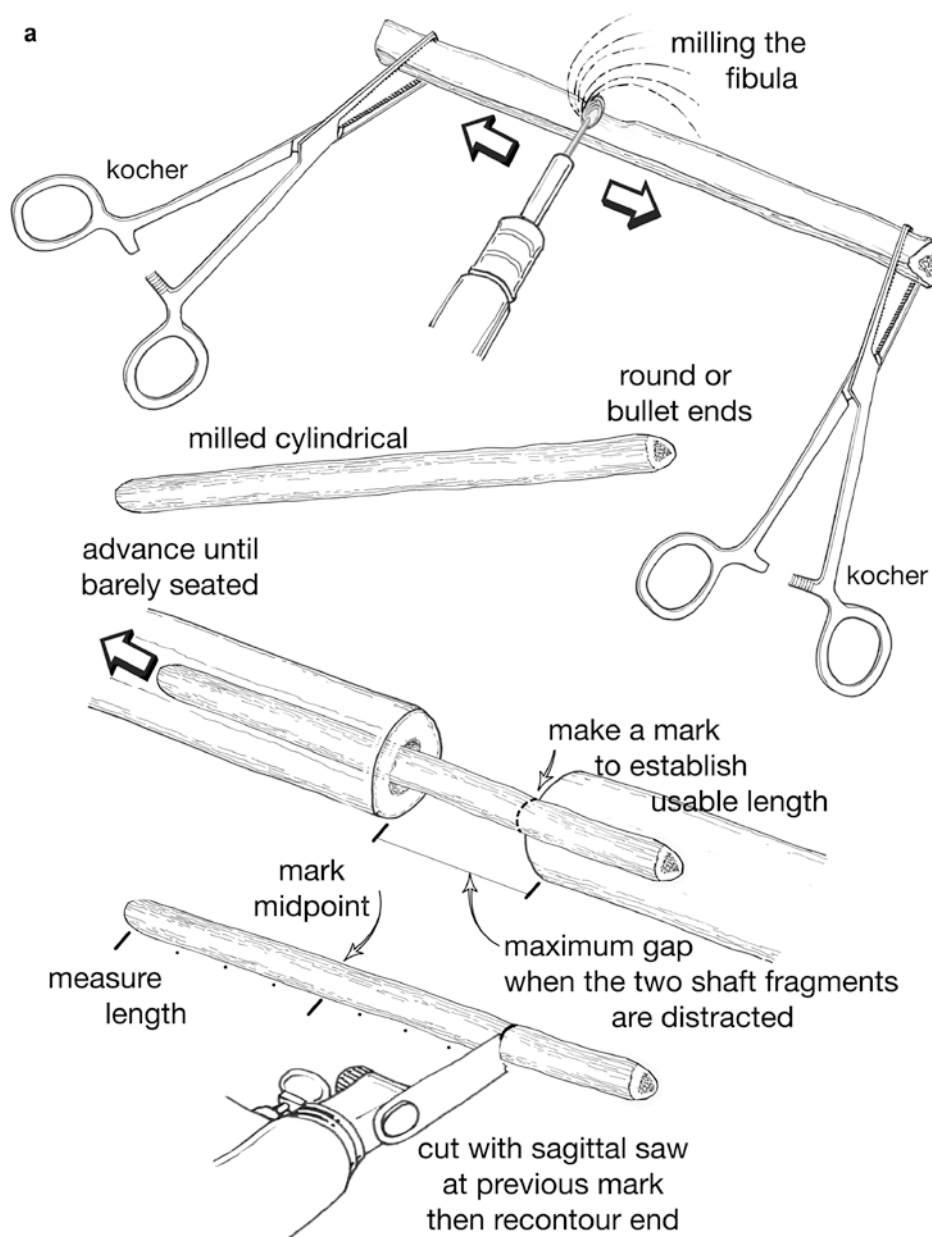
A number of factors influence the direction of the surgical approach, including prior fixation, bone quality, and the medical status of the patient. As discussed in Chap. 10, I generally

approach mid to proximal fractures anterolaterally, but I prefer a posterior approach for mid to distal humeral fractures.

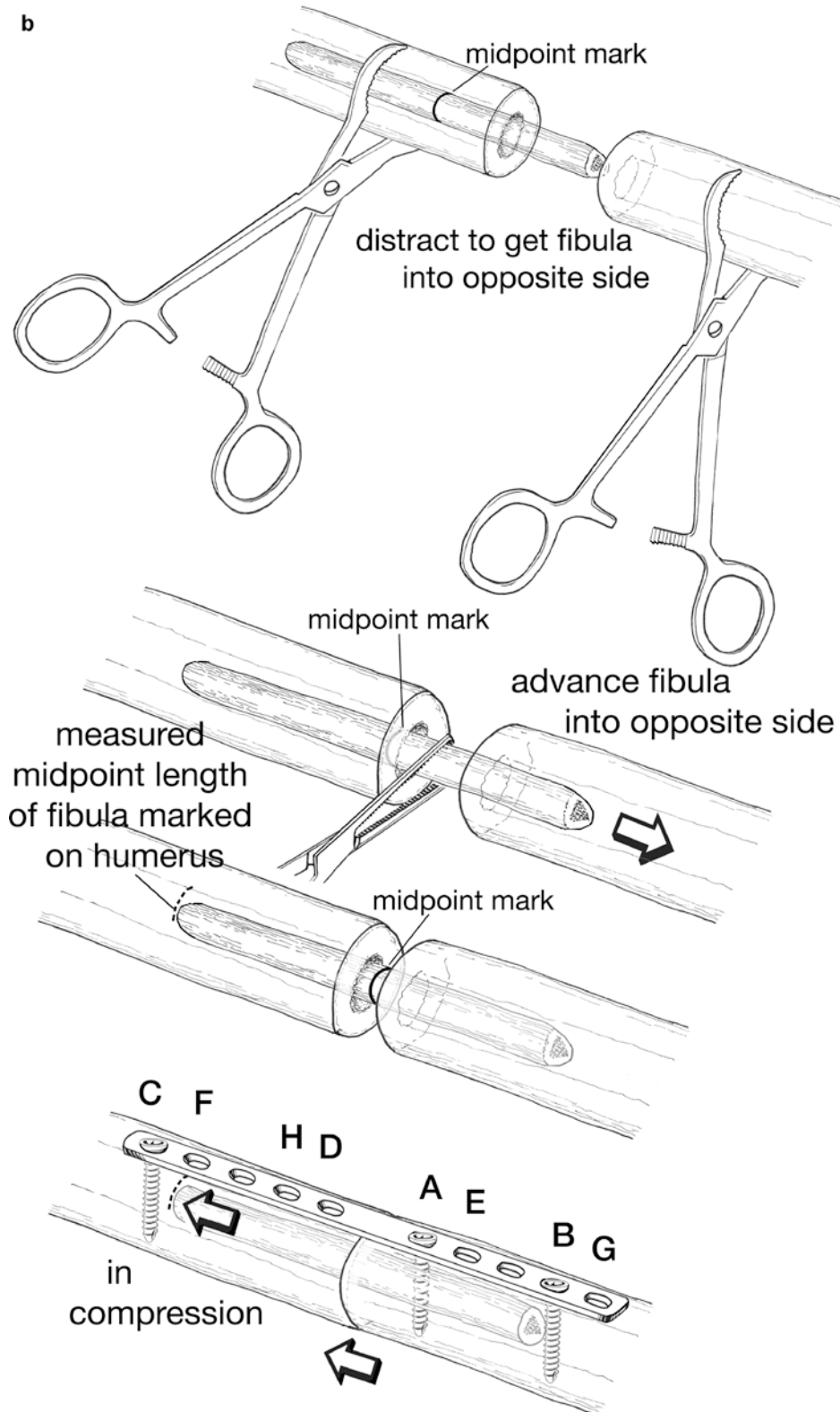
### 11.2.1 Fibular Grafting

The IM preparation is similar with either approach. The fracture generally requires a bit more mobilization than in the acute scenario. The nonunion is prepared with curetting and establishment of the medullary canal. To confirm that a nonunion is not septic, cultures are obtained. Acknowledging the time frame for growing cultures, inflammatory markers are usually obtained preoperatively. The status of the nonunion can direct the decision-making, including purulence, granulation tissue, and/or sinus tracts—factors that may potentially require staged procedures.

Having made the decision to proceed with the internal fixation and fibular grafting, I use a guide wire and then ream both proximally and distally. I try to get the canal diameter to at least 10 mm, if not 11–12 mm. A fibular allograft is soaked in bacitracin solution. Then, using an oval burr, the allograft is milled in a fashion to essentially create a dowel (Fig. 11.8).



**Fig. 11.8** (a) Sequence of fibula allograft preparation for intramedullary insertion. (b) Graft insertion and screw insertion sequence. The compression screw must not engage the fibula, so the graft will slide down the canal upon compression

**Fig. 11.8** (continued)

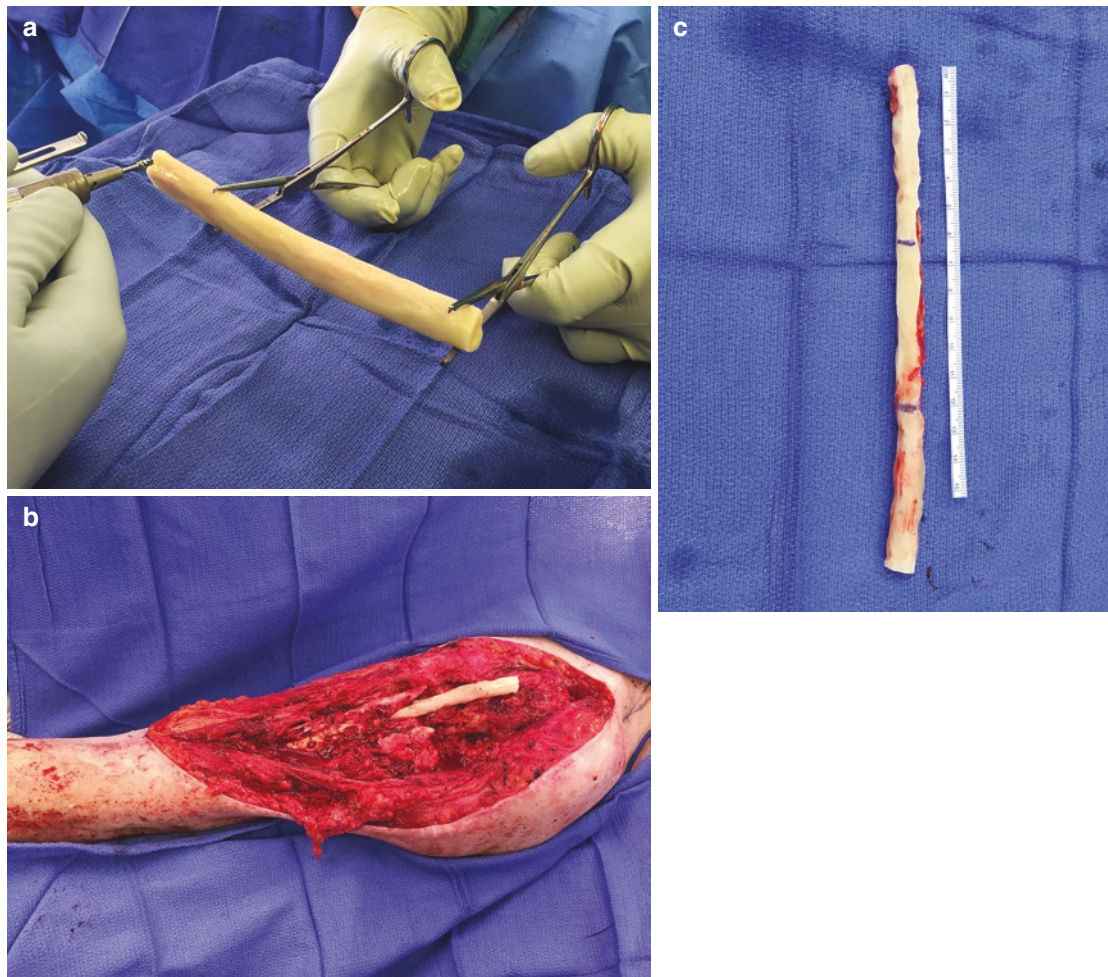


I taper the ends in a bullet fashion to allow easier insertion. Once the canal is prepared, the fibular graft is inserted into the side that allows the greatest length, and then the fracture is distracted to allow the subsequent length to be established. One must be careful not to incarcerate the fibula graft on either end. The graft is then removed after the length is marked, and the fibula is cut, followed by marking the mid-point of the graft. The graft is inserted into the end of the humerus that gives the greatest depth of insertion without incarcerating the graft so that it won't slide back. The fibula is then placed in the other end of

the humerus while distracting. Then, with a series of Kochers, or occasionally a Kirschner wire (K-wire) inserted at a right angle to the fibula to help as a joystick, the fibula can be mobilized into the opposite medullary canal, with the mid-point mark falling at the fracture site. The previously marked mid-point allows assurance that the graft extends an equal distance in both fragments of the nonunion. I like to attain at least 2.5 cm of allograft on either side of the fracture. Figures 11.9, 11.10, 11.11, and 11.12 demonstrate a case in which the grafts are inserted distally first, then retrograde into the proximal shaft.



**Fig. 11.9** Radiographs following referral for hardware failure and nonunion of left humeral shaft fracture



**Fig. 11.10** (a) Technique of contouring the fibula graft with an oval burr. (b) Graft inserted distally first, and then marked for length, removed, and cut after the midpoint is marked. (Contouring job could have been a little smoother.) (c) Length and midpoint marked followed by cutting for length



**Fig. 11.11** Intraoperative radiographs following ORIF with intramedullary fibula

**Fig. 11.12** Follow-up radiographs obtained before the patient fell again, causing a fracture distal to the plate. Nonoperative treatment was then agreed upon



If a more proximal fracture is present, then the fibular graft may be inserted through the humeral head and then tamped into

place like an IM nail (Figs. 11.13, 11.14, 11.15, 11.16, 11.17, 11.18, 11.19, 11.20, 11.21, 11.22, 11.23, and 11.24).

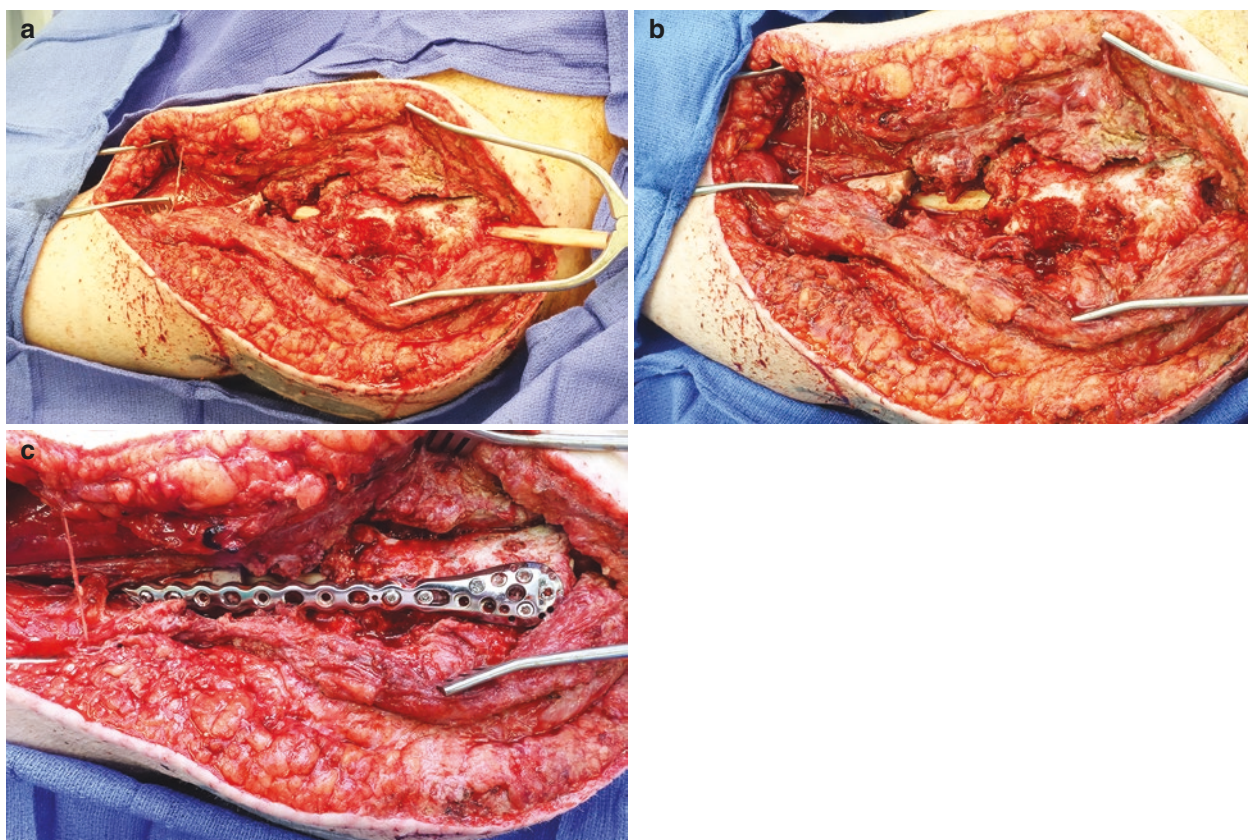
**Fig. 11.13** Presentation radiographs of left humeral shaft fracture in splint





**Fig. 11.14** Radiographs following intramedullary (IM) nailing for nonunion

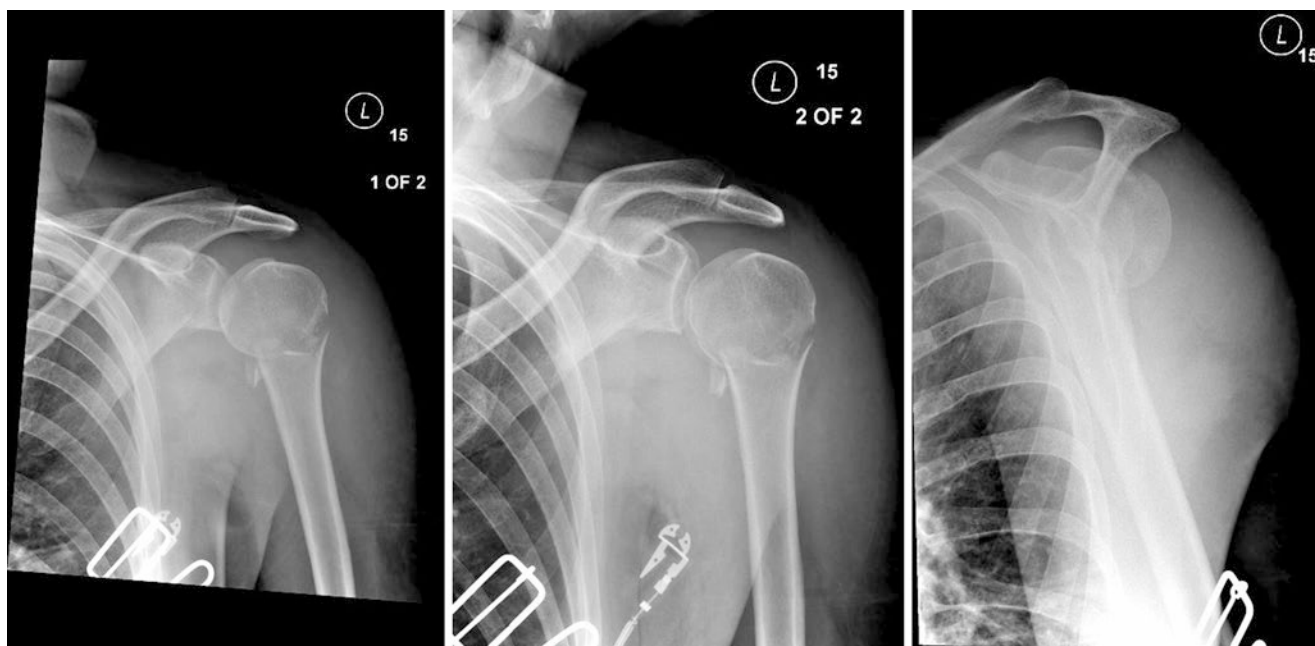




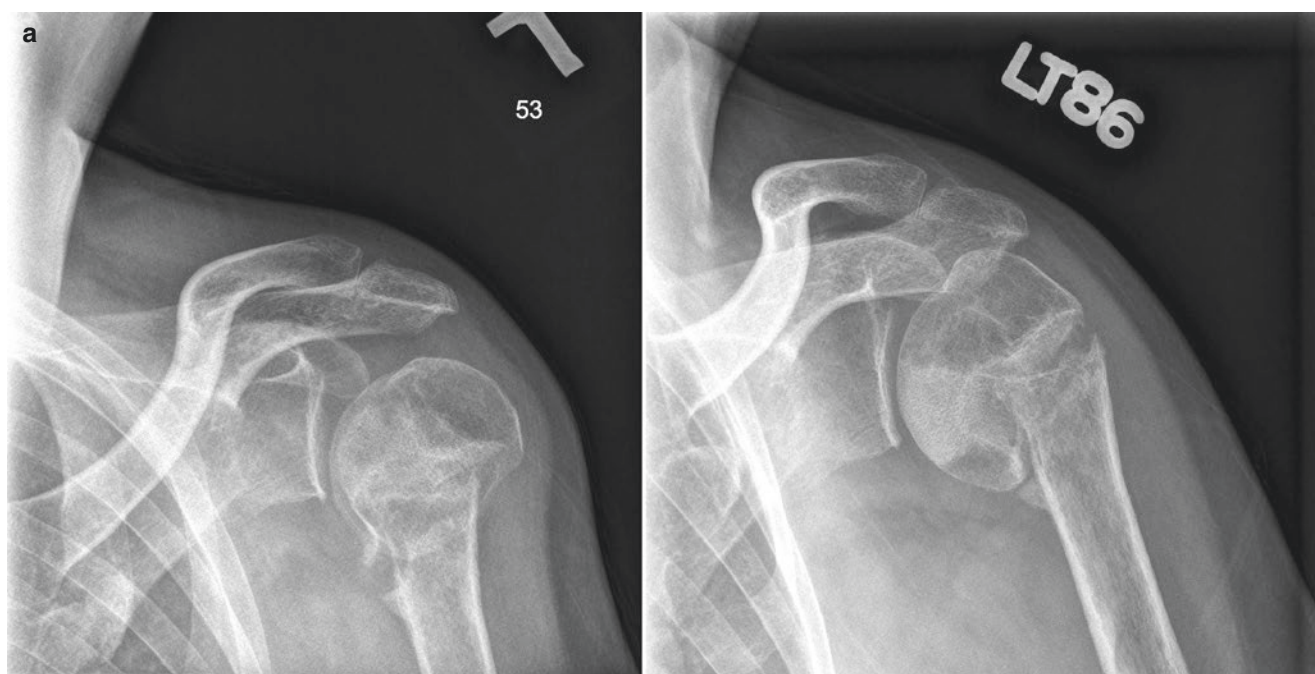
**Fig. 11.15** (a) Nonunion persisted, requiring serial debridements and IM antibiotic nails, followed by ORIF with IM fibula inserted through a previous nail hole proximally. (b) Fibula seated. (c) ORIF with long proximal humeral plate prior to cancellous bone grafting



**Fig. 11.16** Radiographs with IM fibula following ORIF for infected nonunion

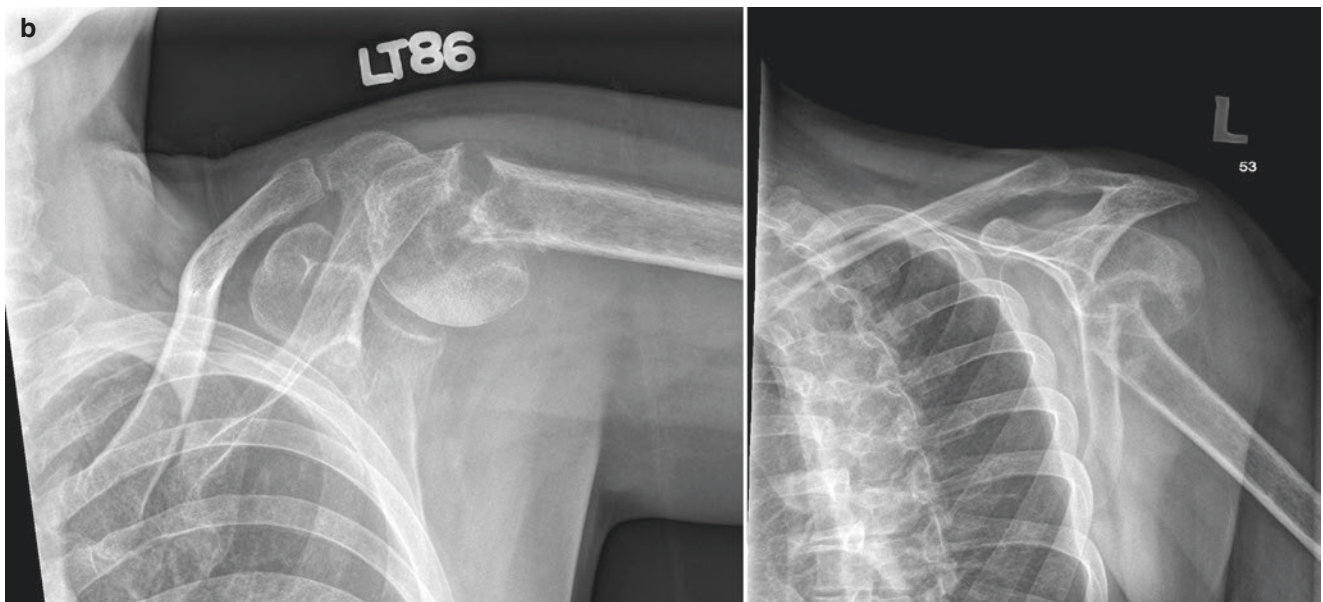


**Fig. 11.17** Radiographs of left proximal humeral fracture in a patient unable to undergo surgical intervention because of carotid injury

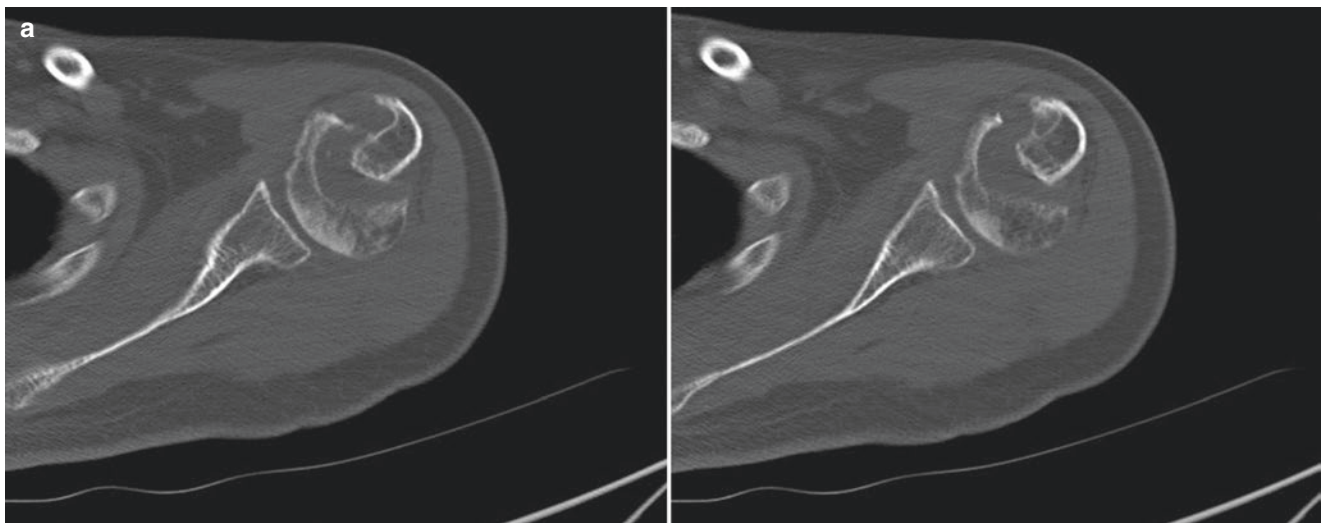


**Fig. 11.18** (a) Follow-up radiographs demonstrating development of nonunion. (b) Abduction and adduction radiographs revealing motion at nonunion

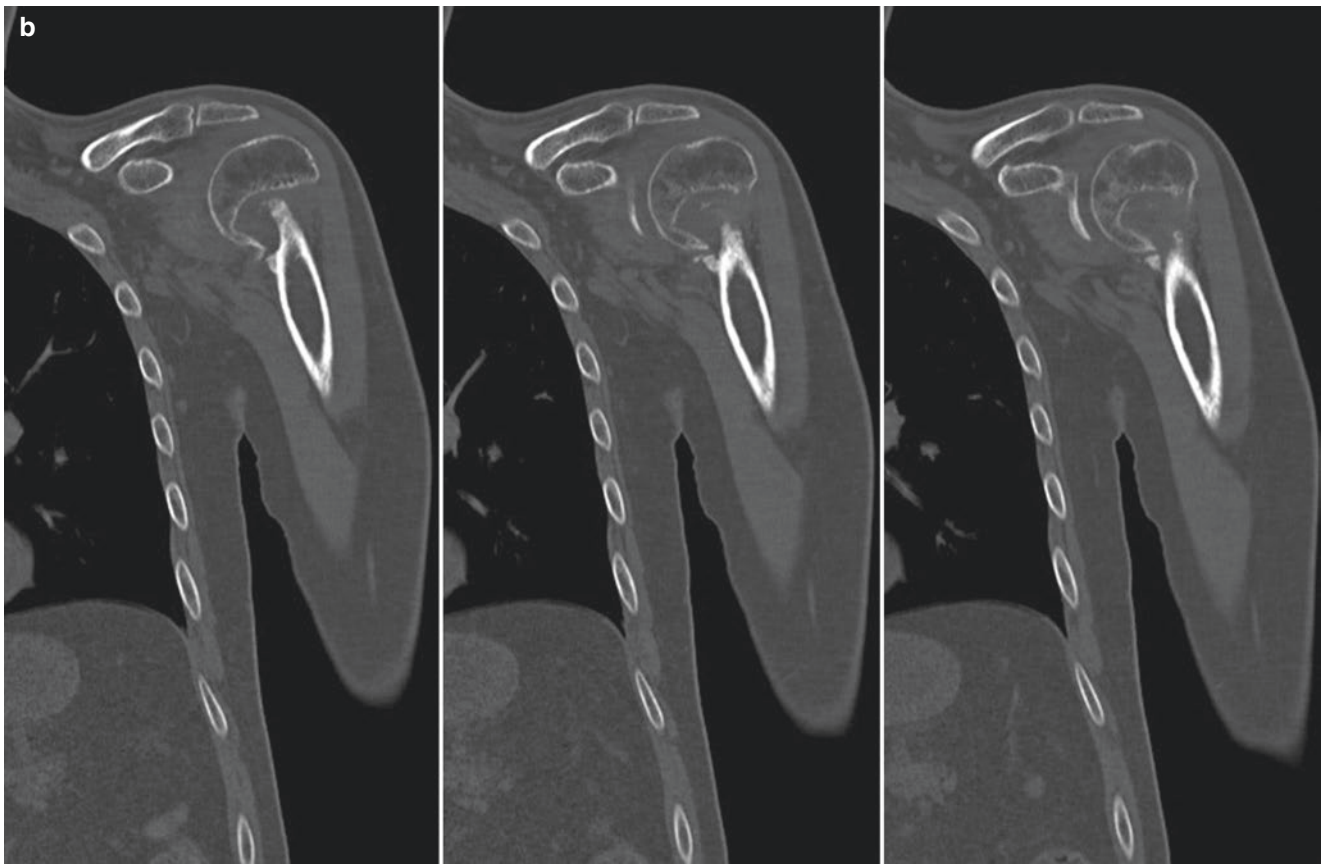




**Fig. 11.18** (continued)



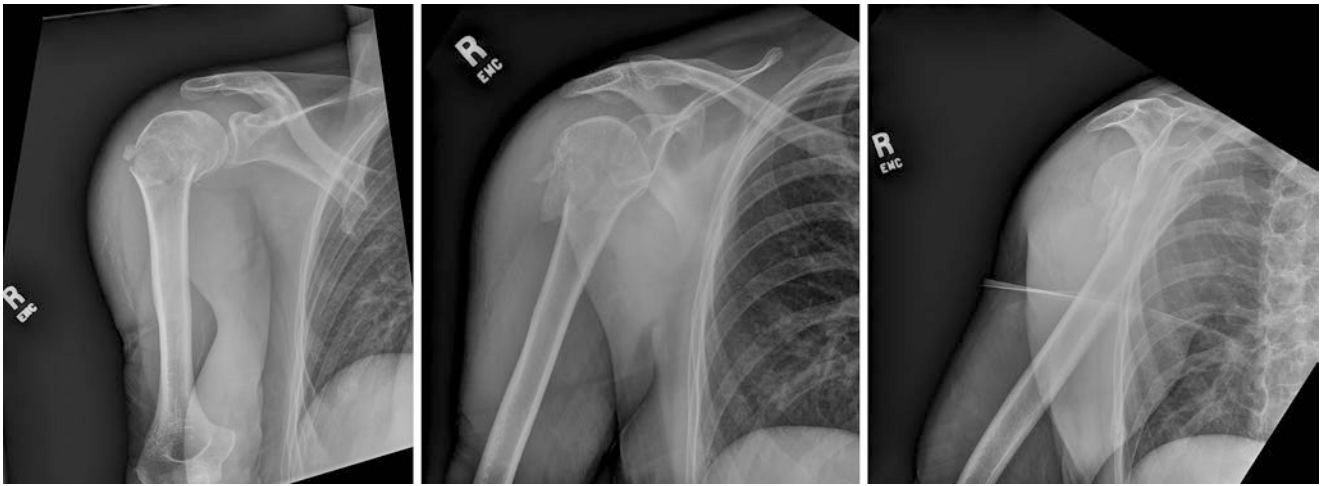
**Fig. 11.19** (a) Axial CT scan revealing nonunion and bone loss in the humeral head. (b) Coronal CT scan revealing bone defect in the humeral head



**Fig. 11.19** (continued)



**Fig. 11.20** Radiographs following ORIF with intramedullary fibula inserted through the head of the humerus

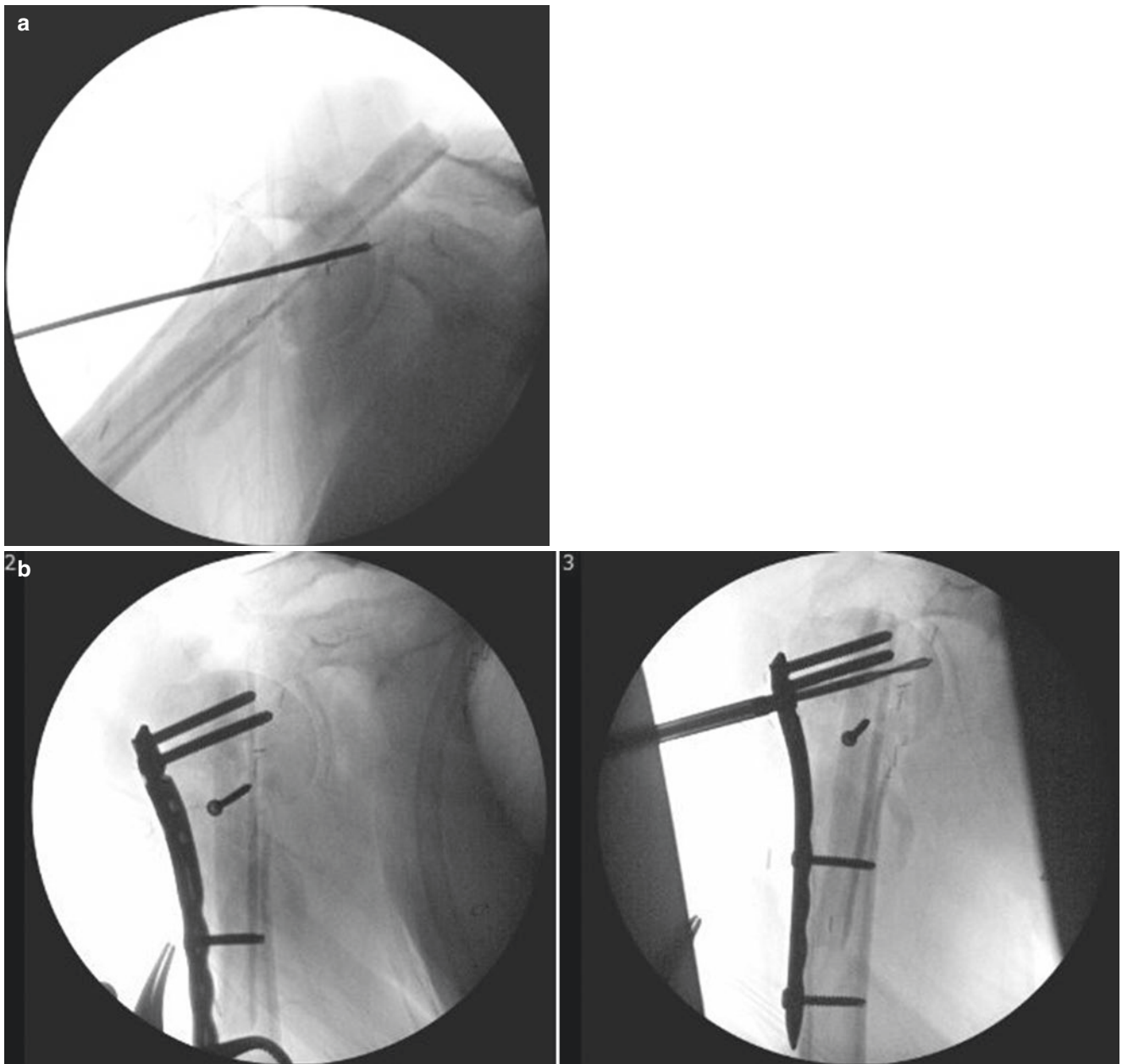


**Fig. 11.21** Radiographs of right proximal humeral fracture initially treated nonoperatively

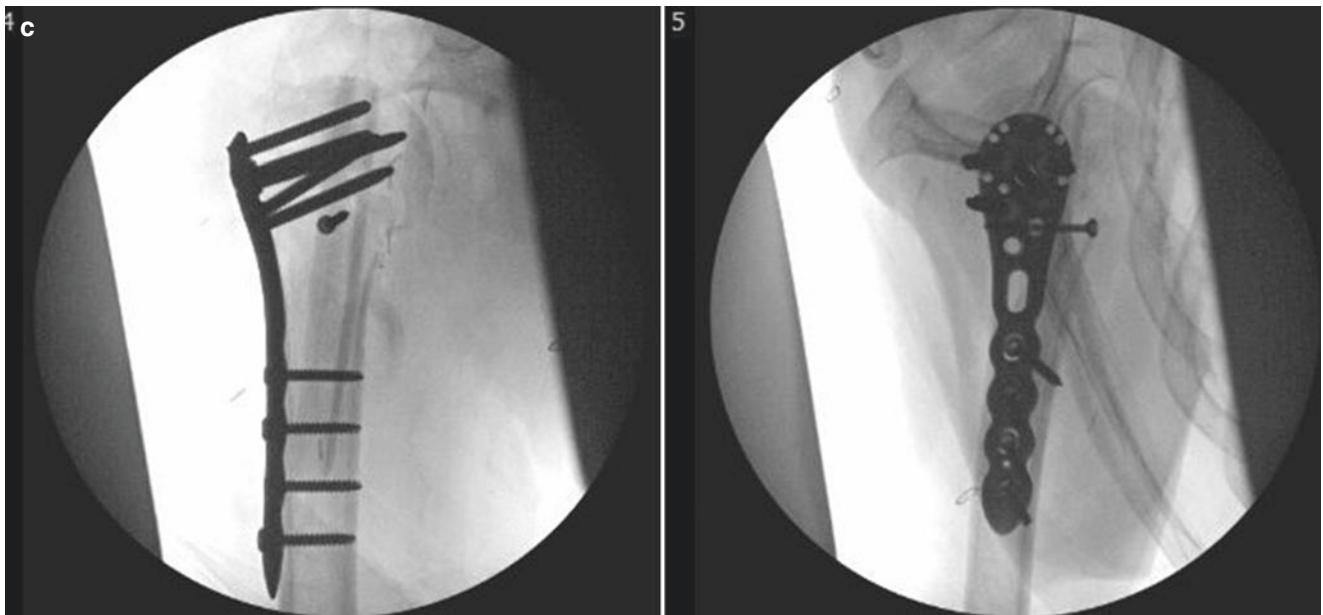


**Fig. 11.22** Radiographs revealing development of nonunion

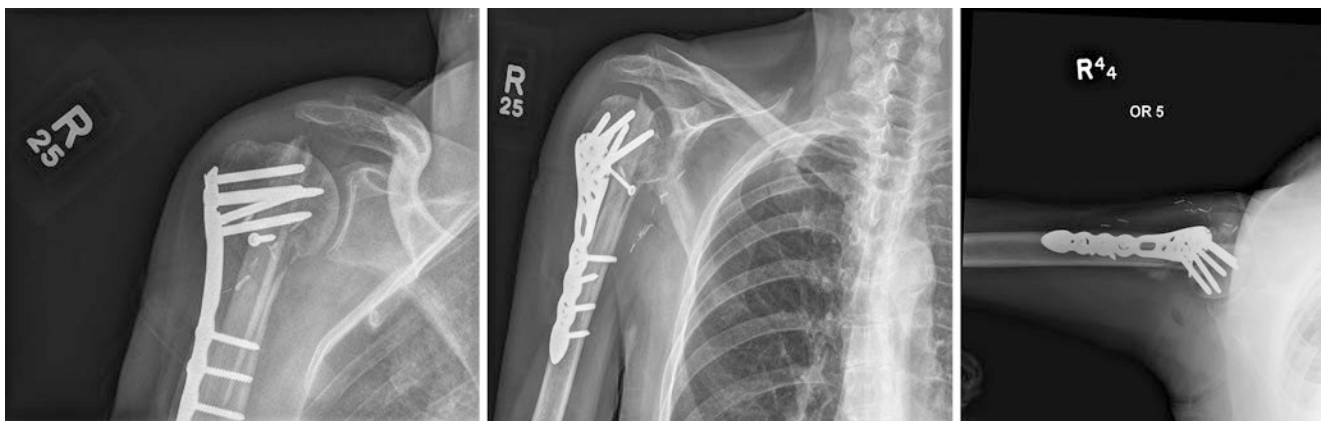




**Fig. 11.23** (a) Intraoperative C-arm radiographs of sequence of fixation using intramedullary fibula beginning with Kirschner wire (K-wire) fixation of the fibula. (b) Fibula cut and stabilized with anterior-to-posterior screw, then plate fixation. (c) Final intraoperative C-arm radiographs



**Fig. 11.23** (continued)



**Fig. 11.24** Follow-up radiographs with apparent prominent fibula despite burring fibula below the level of the cartilage

### 11.2.2 Internal Fixation

Once the fibular graft is in place, the internal fixation can be carried out. I use locking plates, particularly with fractures that extend into the metaphysis. Locking screws are to be used only at the end of the plate in the metaphysis.

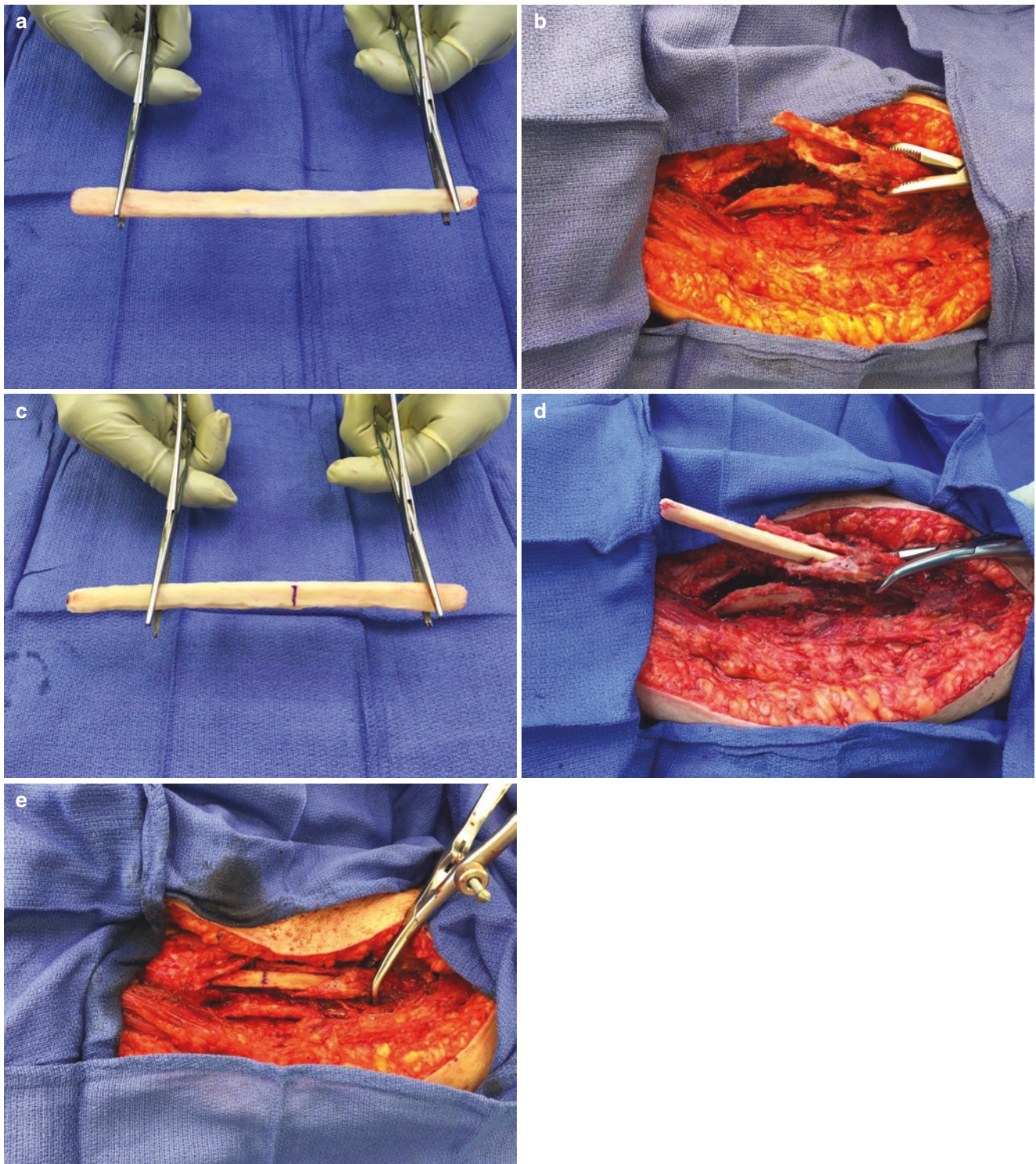
It is important to pay attention to the steps in compression. The fixation will begin on one side of the humerus, with the screws to secure the plate, humerus, and allograft. The opposite compression side must be approached carefully,

because your compression screw needs to be outside of the fibular allograft to allow the graft to slide to some degree on compression. It is important, therefore, to have marked the humerus, or the length of the fibula, to make sure that you are outside the fibula. If not, a radiograph must be obtained to locate the end of the fibula. Once compression is applied, the remaining screws can be inserted in the appropriate fashion. In the osteoporotic patient, I will generally use cancellous bone allograft along with a BMP product such as Infuse® (Figs. 11.25, 11.26, 11.27, 11.28, 11.29, and 11.30).



**Fig. 11.25** Proximal humeral shaft and neck fracture in splint after attempted nonoperative treatment by a referring physician. Radiographs demonstrate nonunion

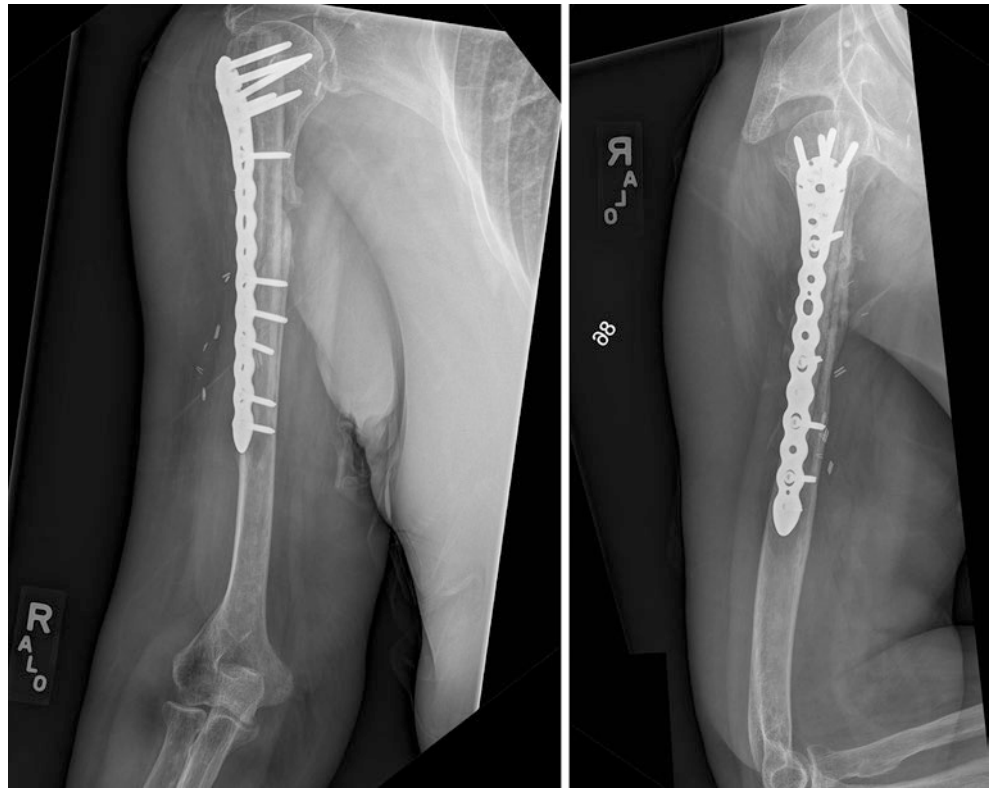




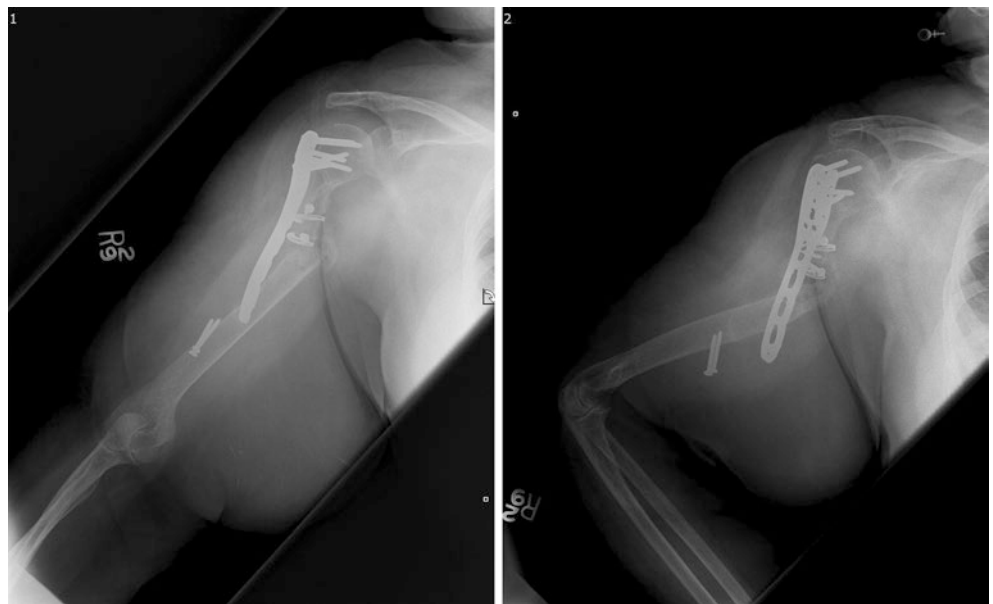
**Fig. 11.26** (a) Fibula prepared prior to insertion to determine length. (b) Humerus prepared, with distal shaft in lobster-claw clamp. (c) Graft marked at point the short end will be maximally seated in the proximal

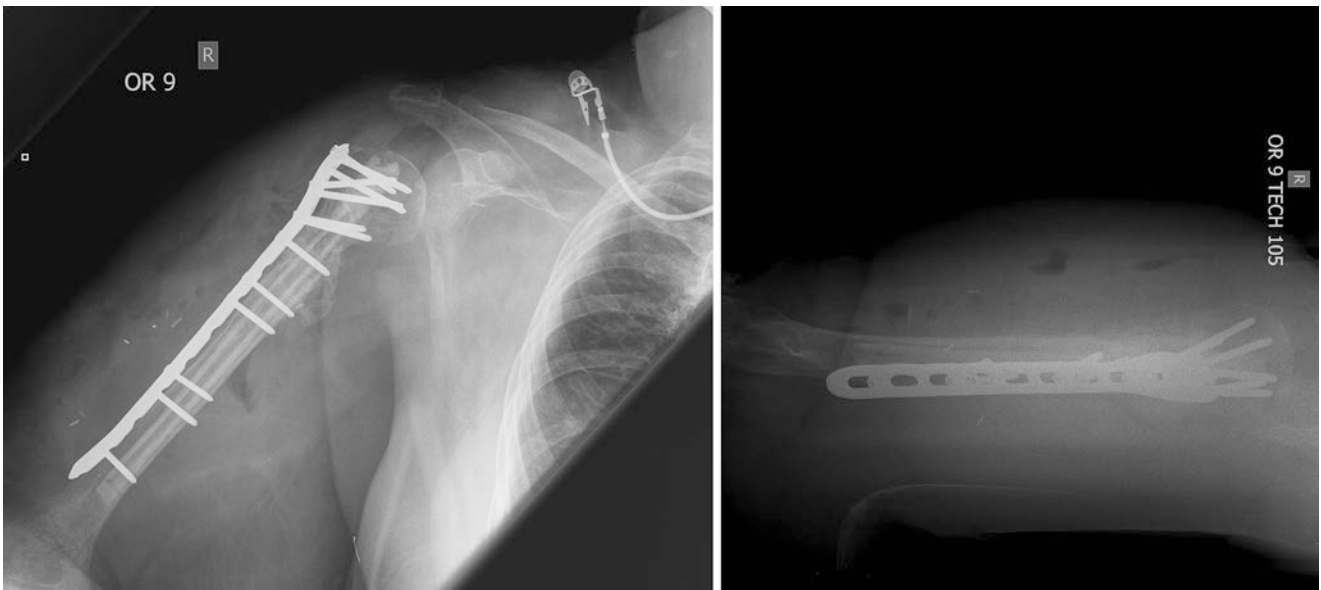
side of the humerus. (d) Graft inserted distally. (e) Graft advanced and seated proximally

**Fig. 11.27** Radiographs at time of discharge, with callus noted anteriorly. The compression screw was the most distal screw in the plate, just distal to the fibula graft



**Fig. 11.28** Radiographs on referral of a right humeral fracture after failed ORIF





**Fig. 11.29** Intraoperative radiographs following hardware removal and ORIF with IM fibula inserted through the fracture and fixation without compression



**Fig. 11.30** Radiographs at time of discharge



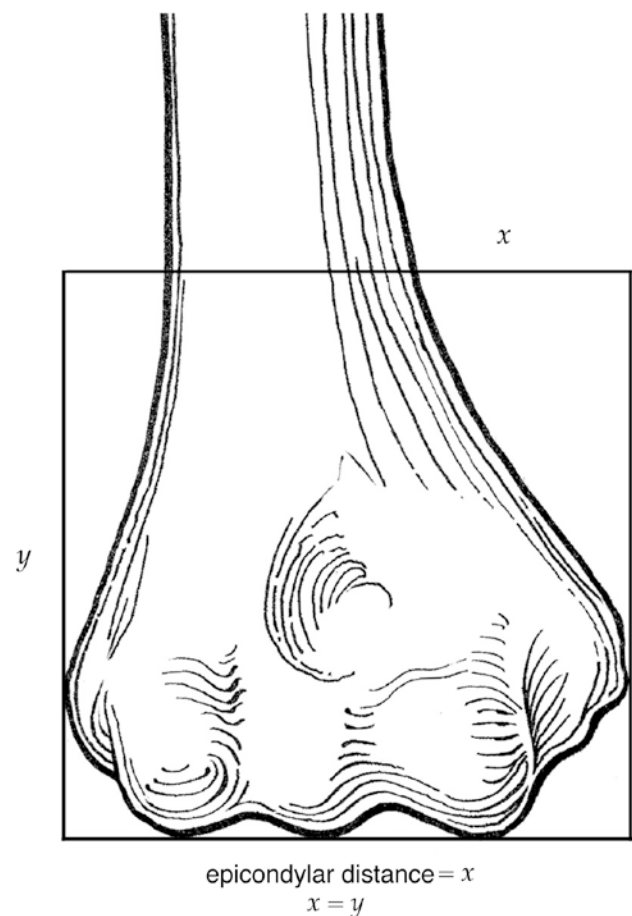
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## 12.1 Fracture Patterns

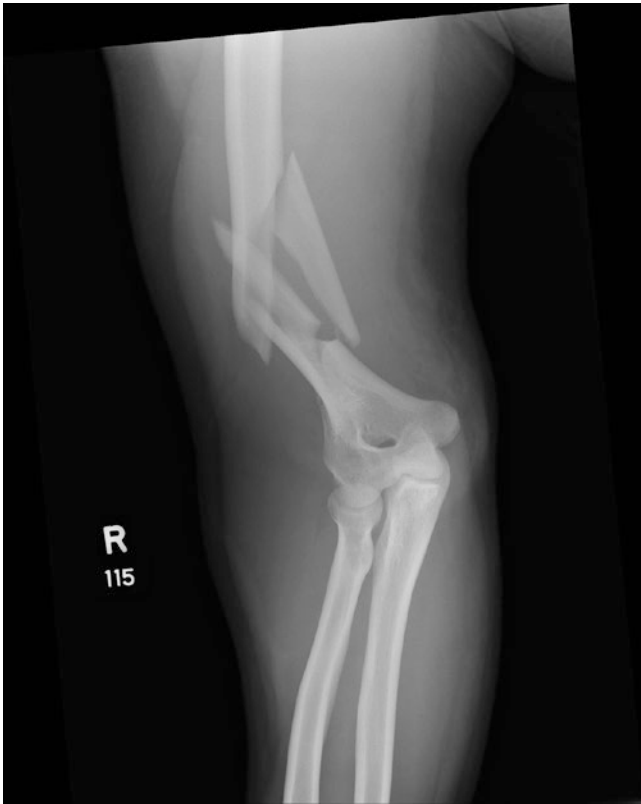
Supracondylar fractures of the distal humerus by definition are not intra-articular and have an extension of the fracture within the metaphysis set forth by the transepicondylar distance. The distance between the epicondyles is determined

and used to construct a square with the distal side of the square or box at the most distal portion of the trochlea. Fractures extending or falling into the box are defined as supracondylar fractures. Those above are shaft fractures. The definition is not specific to the elbow or distal humerus; it can be applied to any bone (Fig. 12.1).

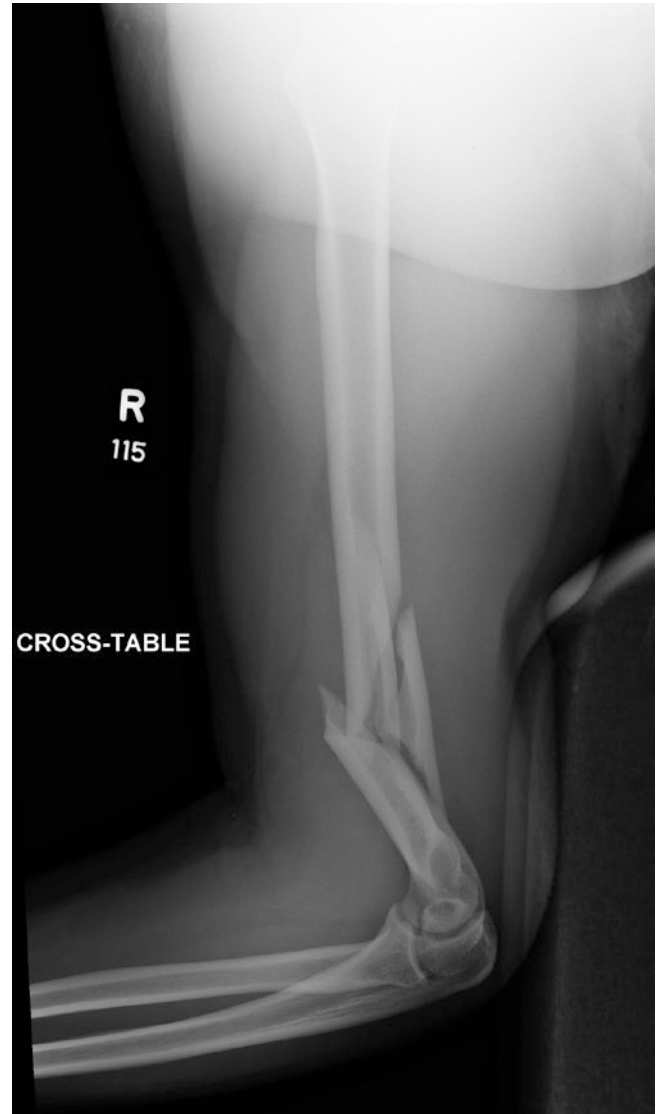


**Fig. 12.1** Delineation of definition of supracondylar fracture: Fractures falling within a square with sides equal to the transepicondylar distance (not unique to the distal humerus)

The fracture pattern is usually spiral or oblique, commonly with a butterfly fragment (Figs. 12.2 and 12.3).



**Fig. 12.2** Supracondylar fracture with butterfly fragment



**Fig. 12.3** Supracondylar fracture with butterfly fragment

These supracondylar fractures of the distal humerus are commonly referred to as *Holstein-Lewis fractures*, but I will refrain from using that term because a review of the Holstein-Lewis paper reveals a mixture of fracture patterns, both shaft and supracondylar [1].

Recent studies and meta-analysis demonstrate a high incidence of radial nerve palsy: 24% in one meta-analysis study and 27% in a single-center study [2, 3].



## 12.2 Treatment Options

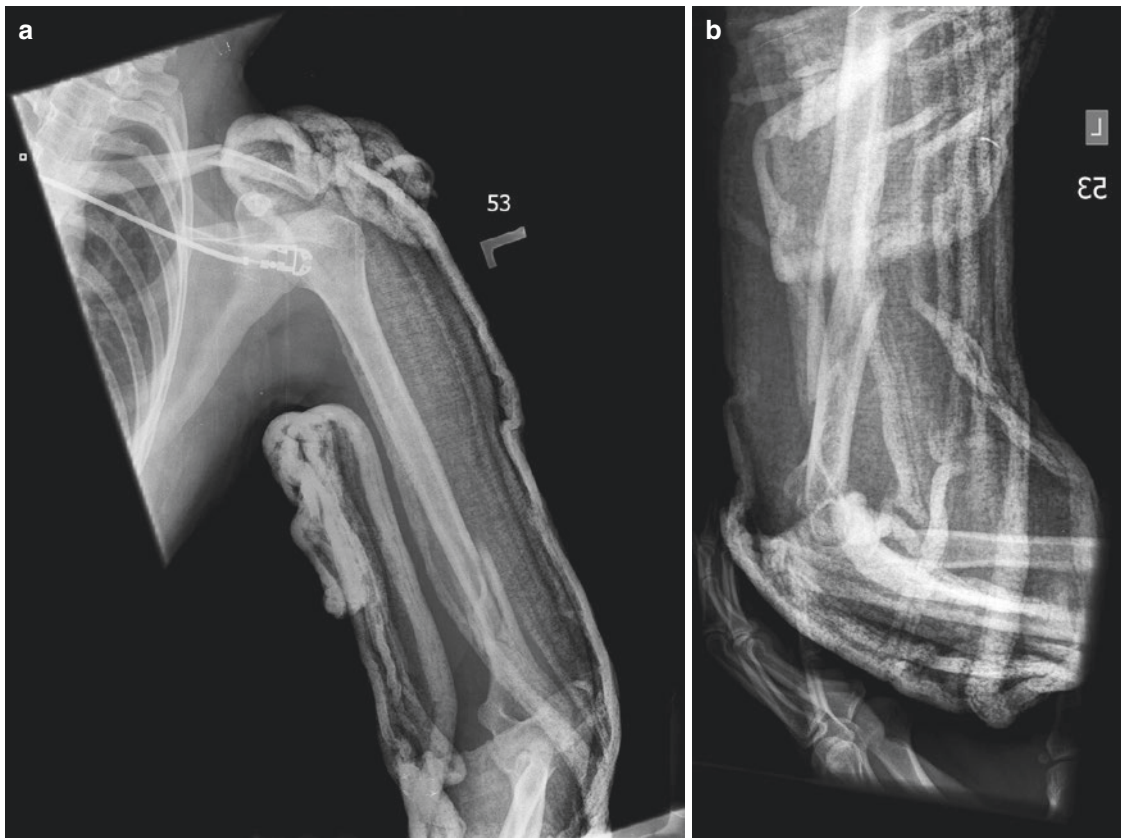
The two main treatment options are nonoperative treatment with splinting, cast, or fracture brace immobilization *versus* open reduction internal fixation (ORIF) [4]. External fixation is rarely used but can be effective [5]. Nonoperative treatment and operative intervention have similar functional outcomes. The nonoperative treatment group will be found to have a residual deformity, whereas the ORIF group will have an increased incidence of postoperative radial nerve palsy, elbow stiffness, and pain [4].

## 12.3 Nonoperative Treatment

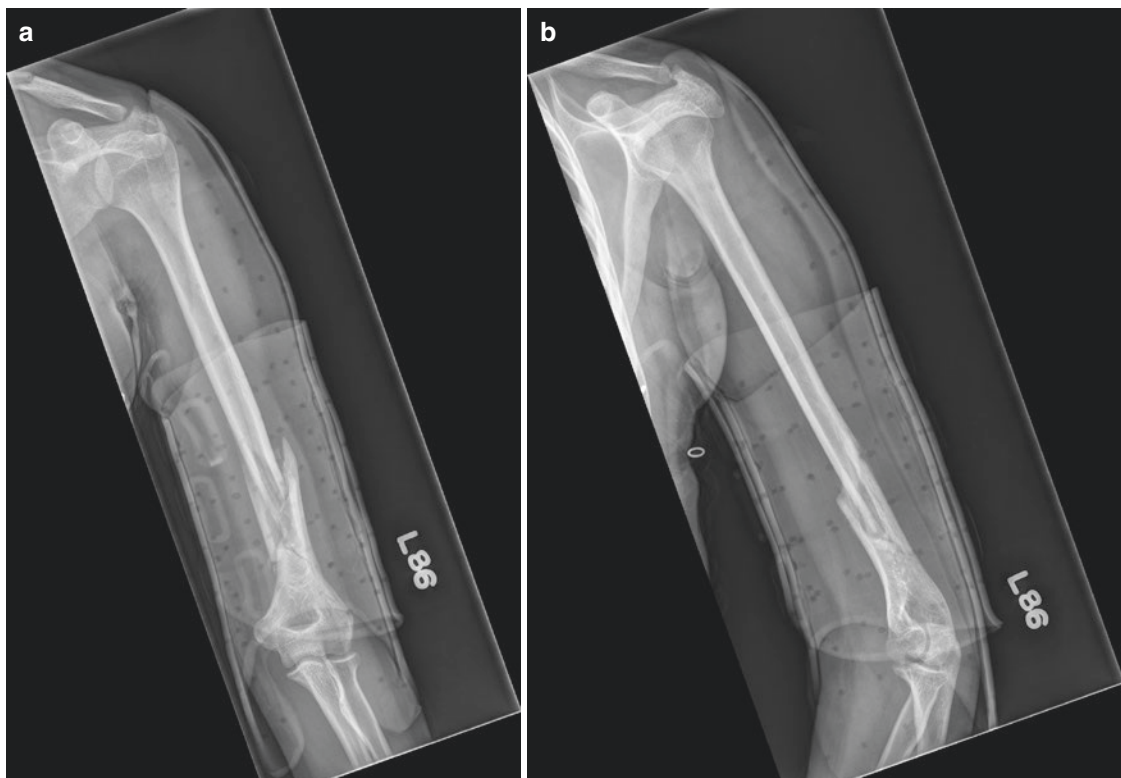
Nonoperative treatment begins with a coaptation splint worn for 7–10 days. I use two 4-inch rolls of plaster with the splint molded to correct for varus deformity. At 7–10 days, I transition the patient to a fracture brace that also has a deformity correction mold. The fracture brace is fabricated to allow elbow range of motion and shoulder range of motion. The patient wears the splint for 3–4 months. This rehabilitation program for distal humerus supracondylar fractures is very similar to the humeral shaft program except that the fracture brace usually does not cap over the shoulder (Figs. 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 12.10, 12.11, and 12.12).



**Fig. 12.4** (a, b) Injury radiographs of left distal humerus fracture

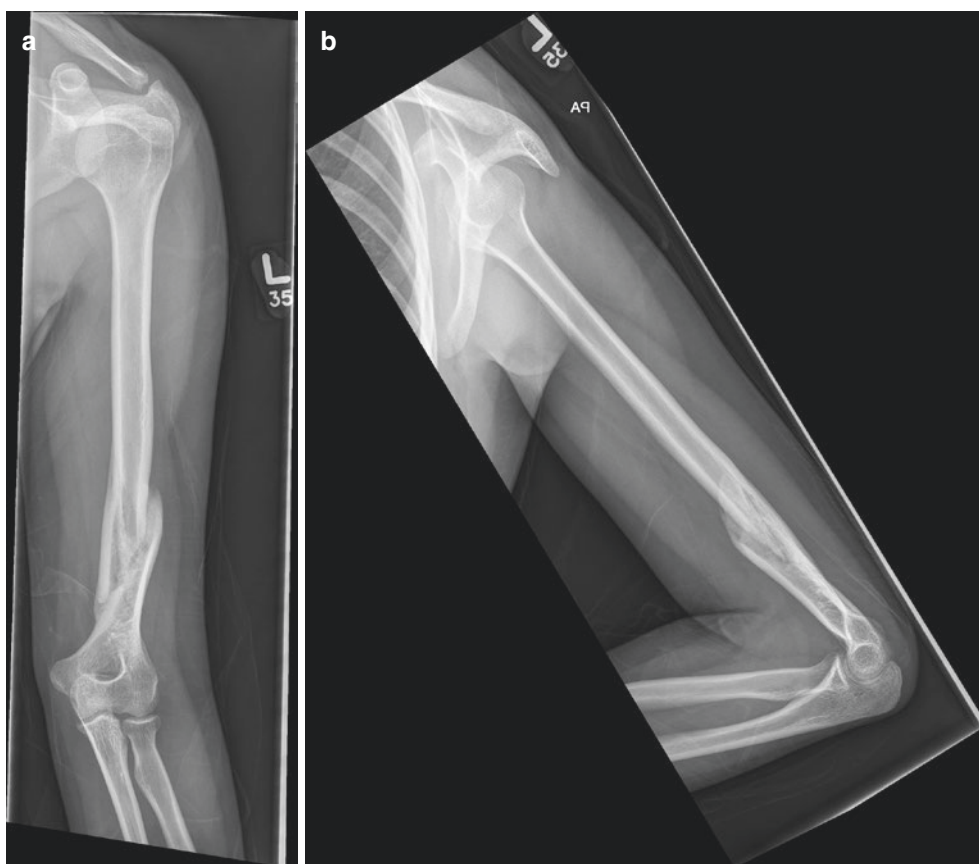


**Fig. 12.5** (a, b) Reduction and splinting radiographs (splint excessive proximally)

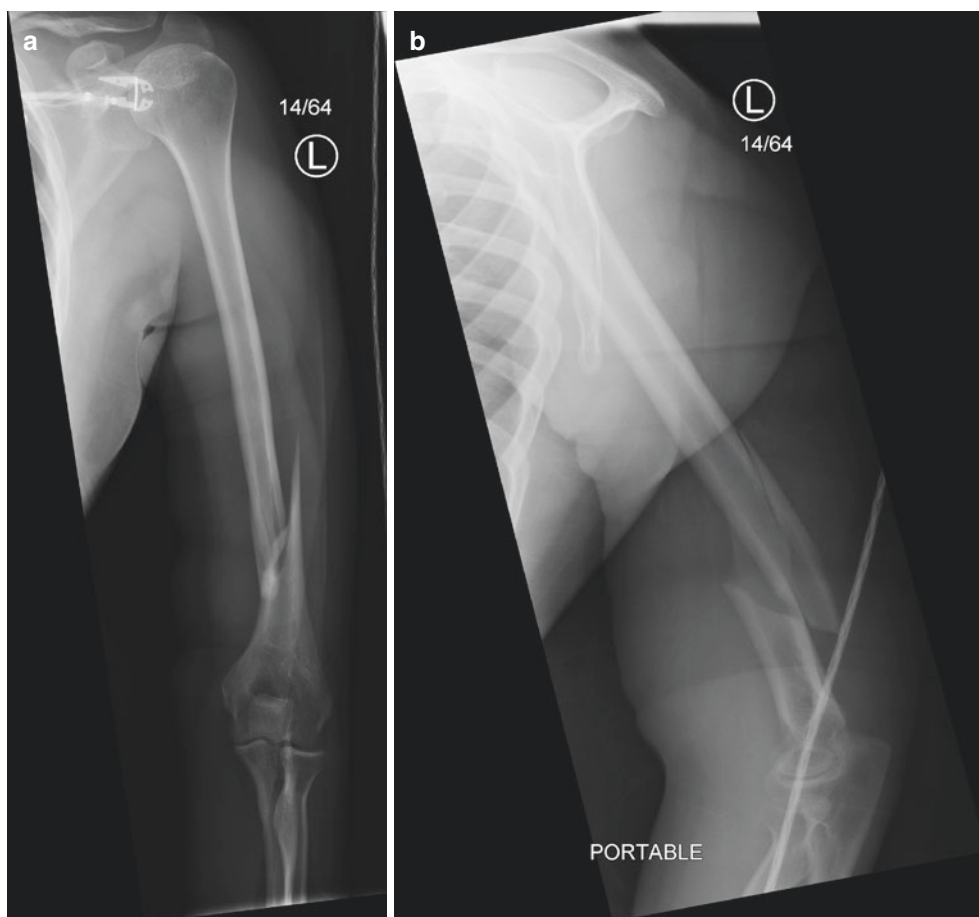


**Fig. 12.6** (a, b) Custom fracture brace with varus still present

**Fig. 12.7** (a) Fracture healed in 12° of varus. (b) Lateral radiograph of healed fracture

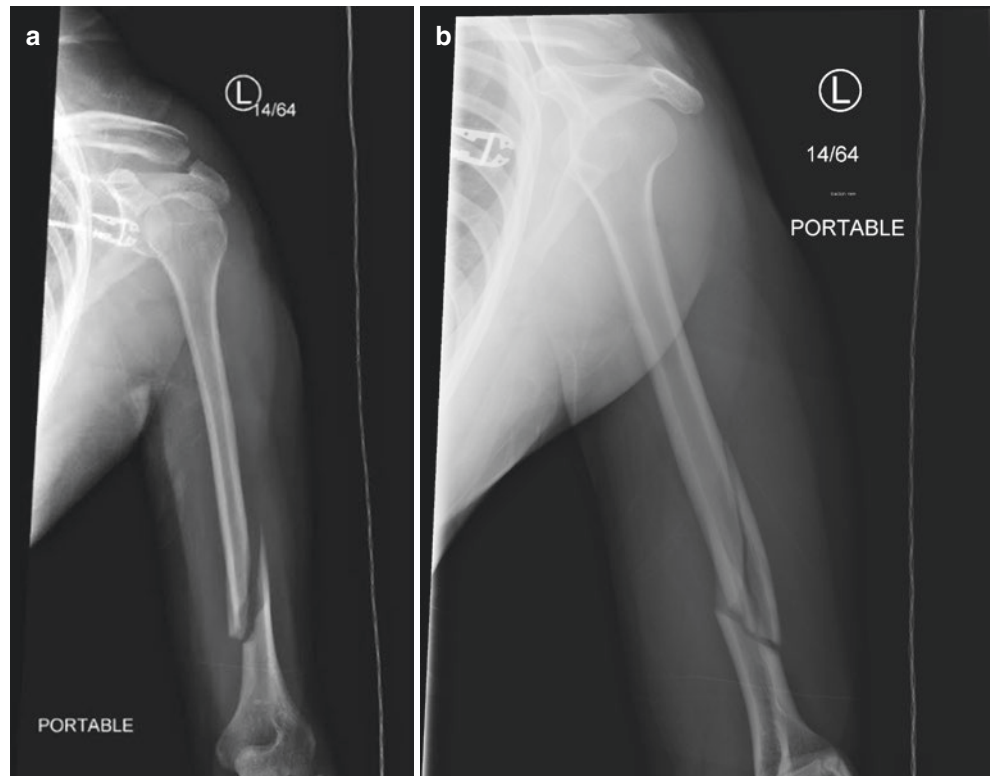


**Fig. 12.8** (a, b) Injury radiographs of left distal humerus supracondylar fracture

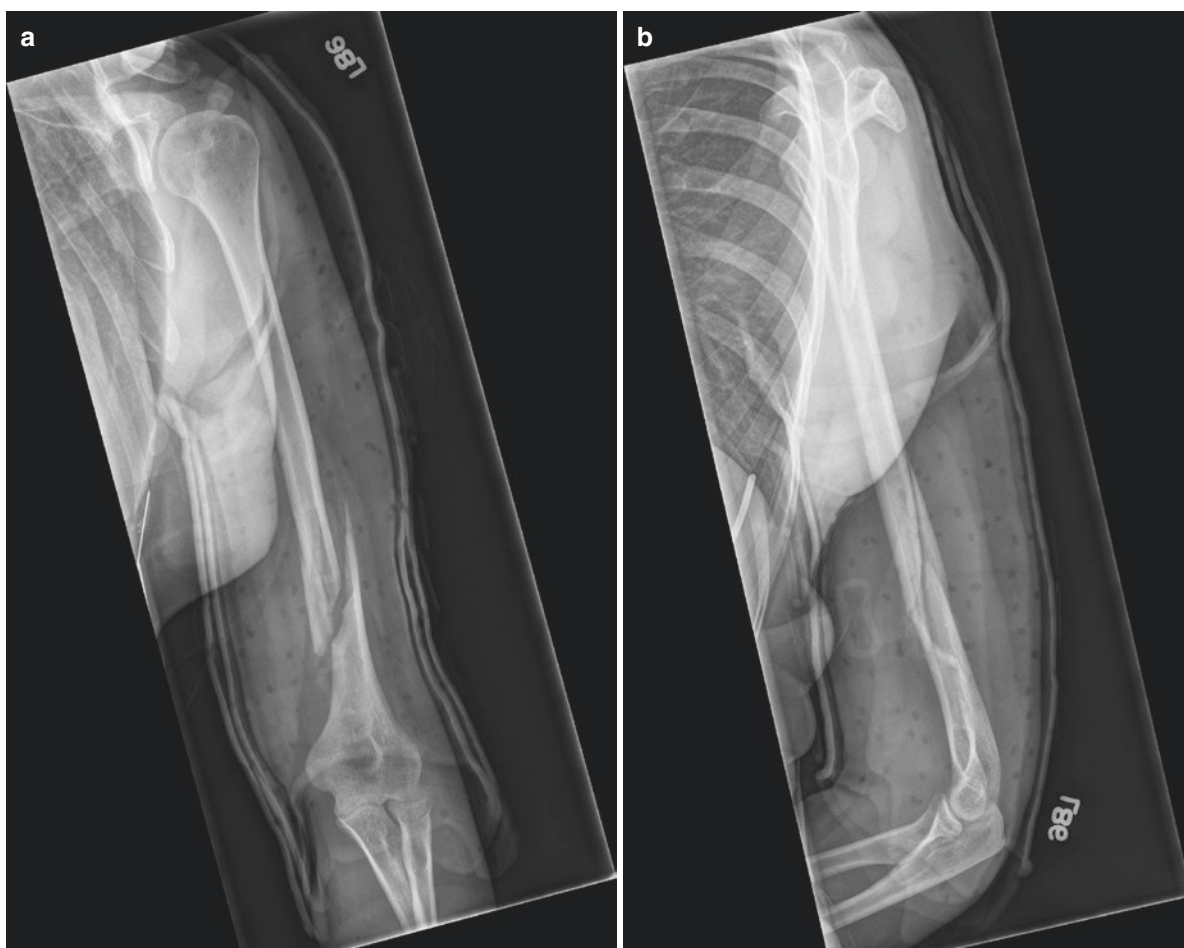




**Fig. 12.9** (a, b) Traction radiographs



**Fig. 12.10** (a, b) Coaptation splint radiographs



**Fig. 12.11** (a, b) Custom fracture brace radiographs



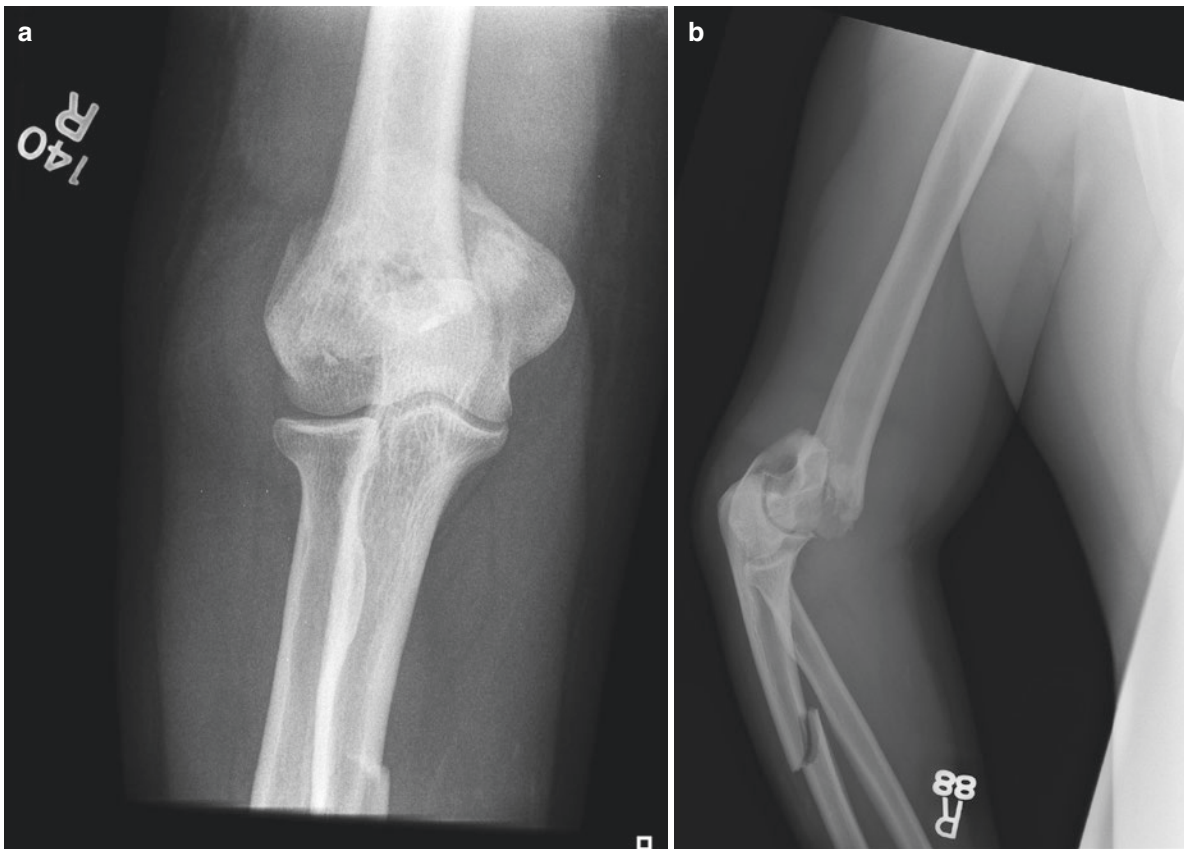
**Fig. 12.12** (a, b) Radiographs of healed fracture at discharge 4 months following injury

## 12.4 Open Reduction Internal Fixation

### 12.4.1 Posterior Approach

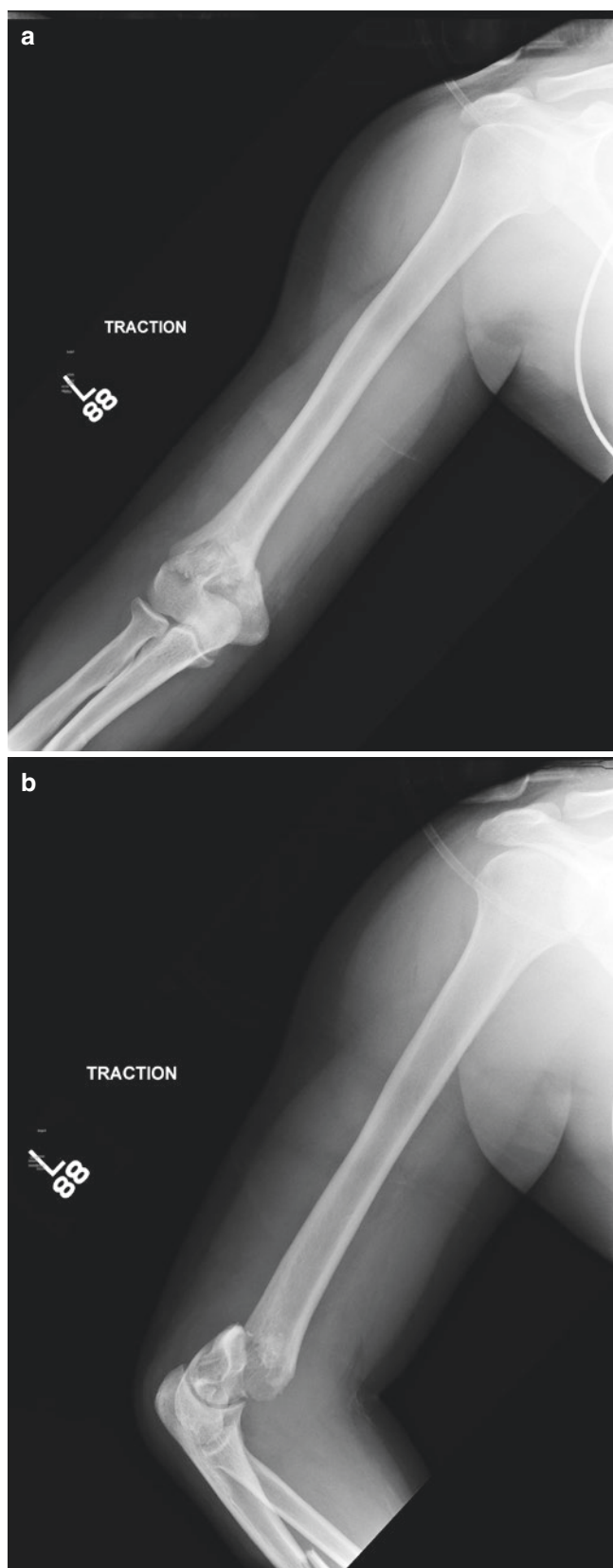
When the patient chooses surgery, the setup, preparation, and draping are the same as for the posterior humeral fracture approach presented in Chap. 10. A posterior approach is used, with the triceps mobilized medially and laterally, similar to the approach to the T-intercondylar fracture but without the osteotomy. This approach is similar to the

approach used for a humeral shaft fracture, but it extends more distally between the triceps and anconeus. Anconeus denervation does occur when this interval is developed. The anconeus receives its innervation from the radial nerve after innervating the medial head of the triceps [6]. Single-plate fixation is performed down the lateral column. Clinical and biomechanical studies have been performed and validate this approach [2, 7, 8]. In very low supracondylar fractures, dual plates can be used (Figs. 12.13, 12.14, 12.15, 12.16, and 12.17).



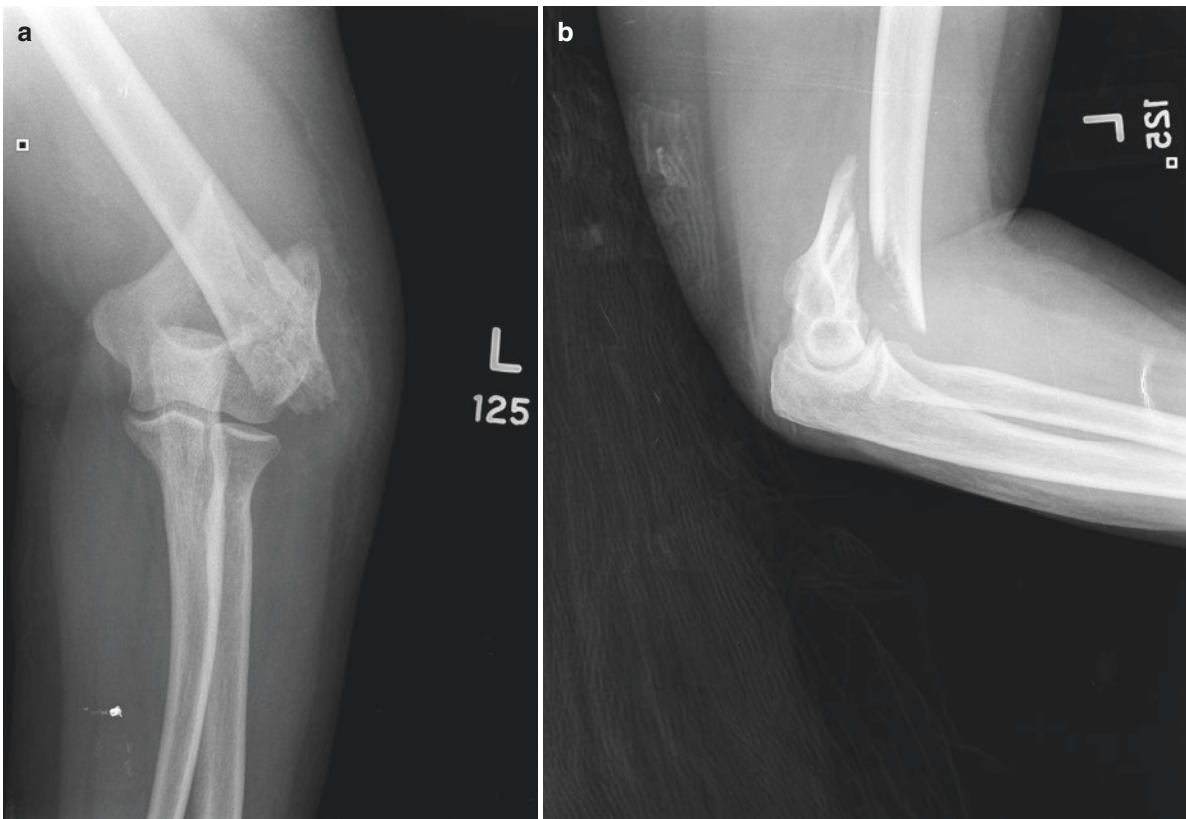
**Fig. 12.13** (a, b) Radiographs of a low supracondylar fracture



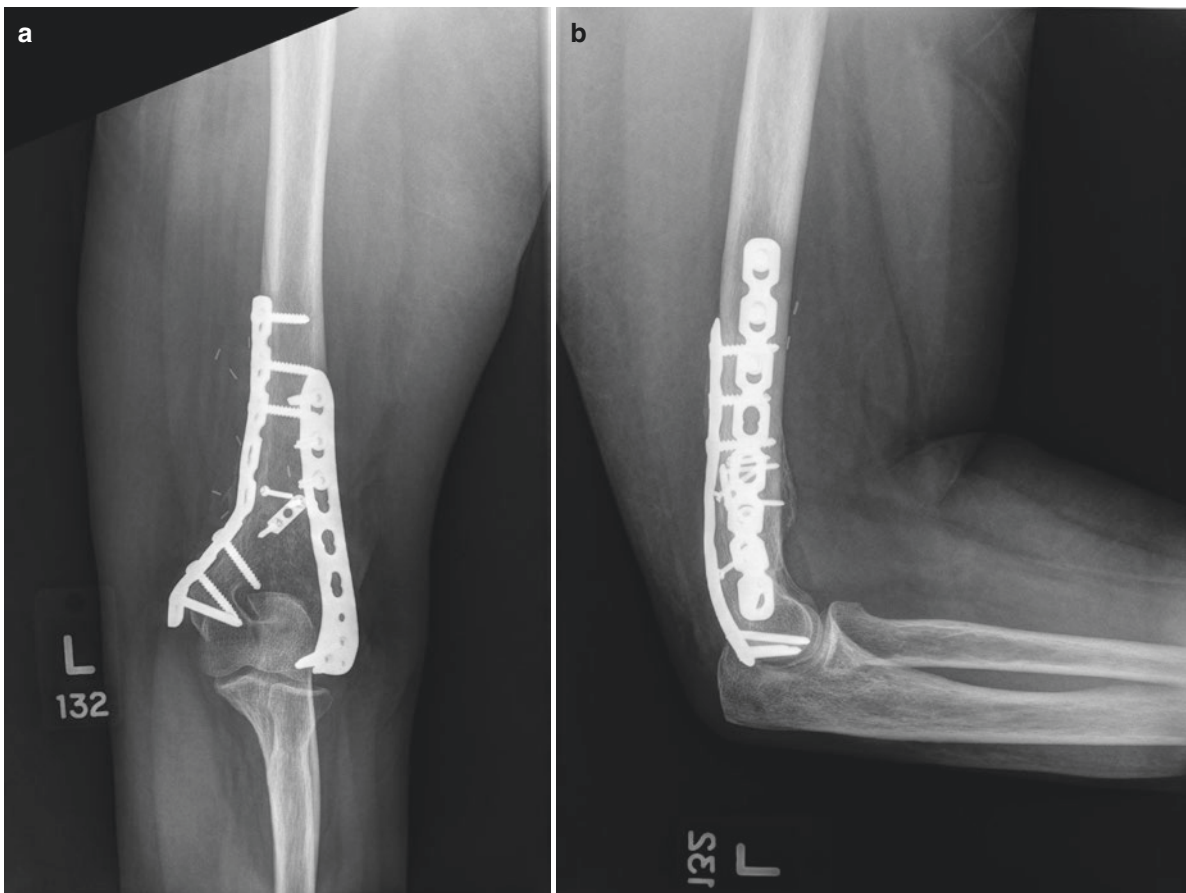


**Fig. 12.15** (a and b) Fixation with dual posterior plates

**Fig. 12.14** (a, b) Traction radiographs demonstrating the supracondylar component medially (misabeled left)



**Fig. 12.16** (a, b) Injury radiographs of low supracondylar fracture with distal exit laterally; thus dual plates would be utilized



**Fig. 12.17** (a, b) Radiographs following open reduction and internal fixation (ORIF)

### 12.4.2 Plate Bending and Cupping

The plate generally utilized was designed and developed to obviate the need for a medial approach and fixation. The

plate design and contour allows for distal fracture fixation without blocking elbow extension (Figs. 12.18, 12.19, and 12.20).



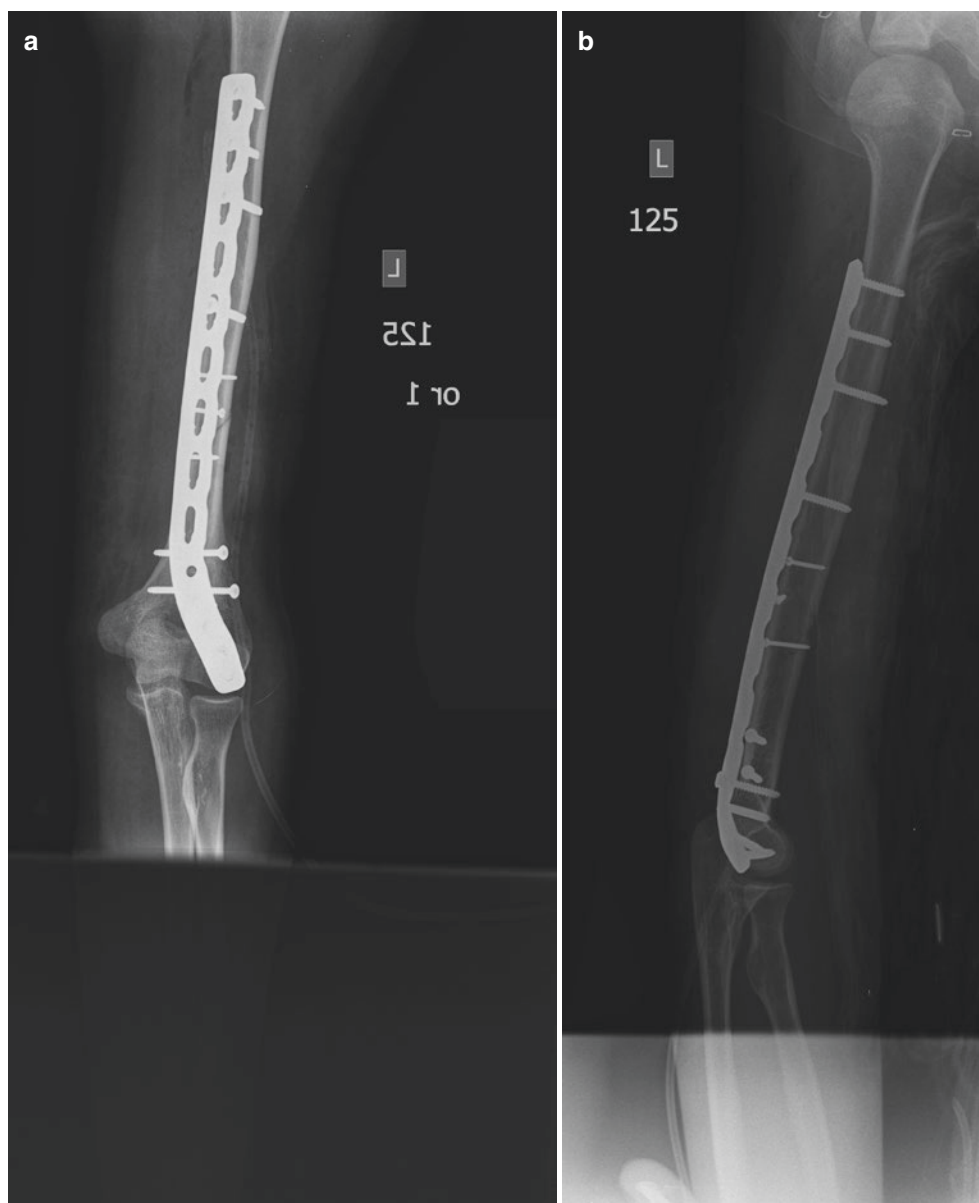
**Fig. 12.18** Injury radiographs of left distal humerus supracondylar fracture



**Fig. 12.19** Injury radiographs of left distal humerus supracondylar fracture

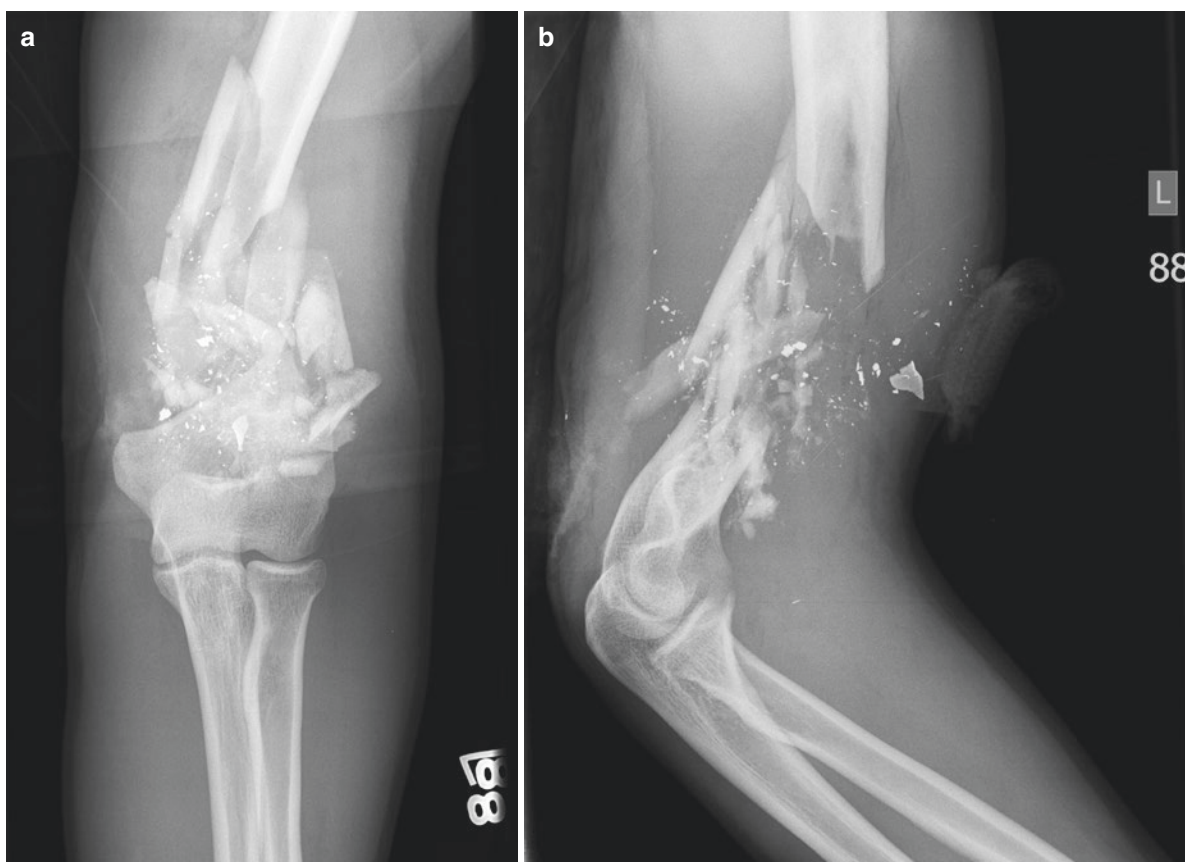


**Fig. 12.20** (a, b) ORIF performed with the fracture-specific plate demonstrating distal position at the plate without blocking extension

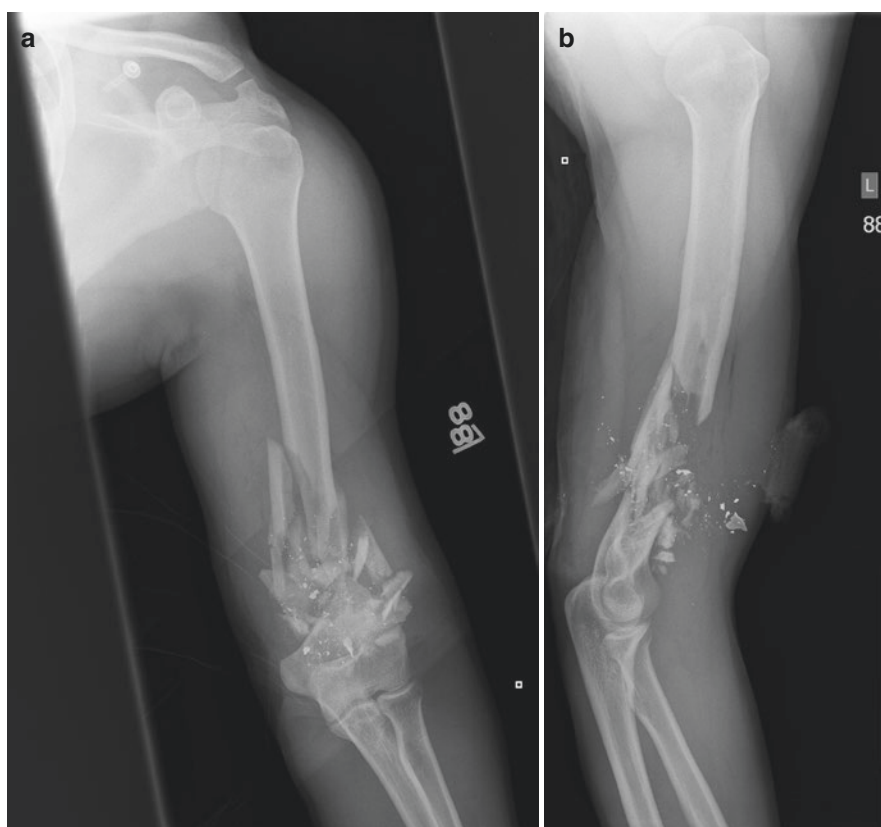


The genesis of the plate concept arose from the need for fixation in patients sustaining gunshot wounds and very distal humeral fractures, which frequently required bending the

existing plates in the coronal plane (Figs. 12.21, 12.22, 12.23, 12.24, 12.25, and 12.26).



**Fig. 12.21** (a, b) Injury radiographs of low supracondylar fracture



**Fig. 12.22** (a, b) Traction radiographs



**Fig. 12.23** Fixation of fracture with contoured limited contact-dynamic compression plate (LC-DCP)



**Fig. 12.24** Fixation of fracture with contoured LC-DCP



**Fig. 12.25** (a, b) Radiographs of right distal humerus fracture following external fixation at referring facility





**Fig. 12.26** (a, b) Fixation with dual contoured LC-DCP fixation

The plate used is a 4.5-mm stock plate with 3.5-mm screws (Figs. 12.27 and 12.28).

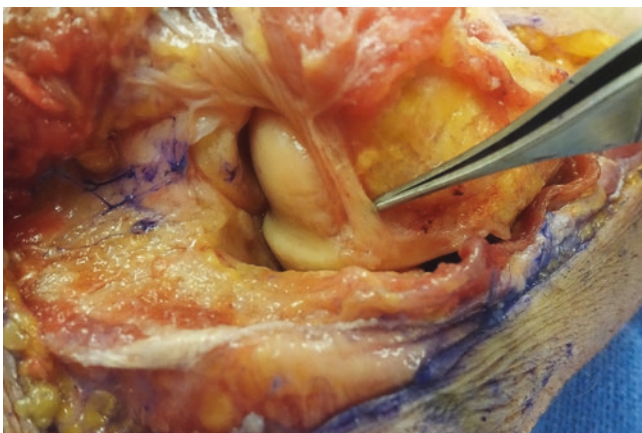


**Fig. 12.27** Left distal humerus supracondylar plate

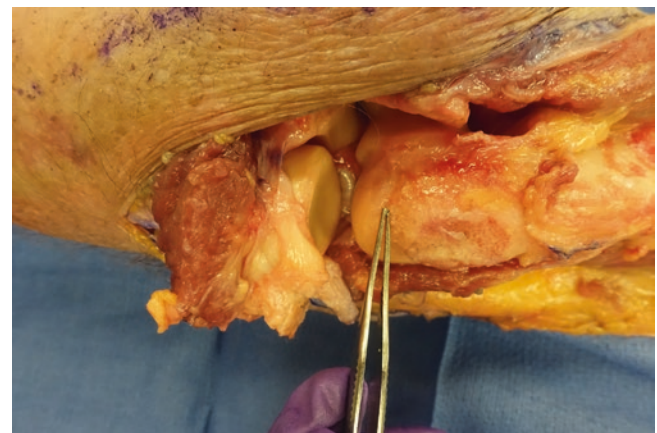


**Fig. 12.28** Left distal humerus supracondylar plate

The intent and concept of the plate was to terminate at the capsule cartilage juncture (Figs. 12.29 and 12.30).



**Fig. 12.29** Capsular reflection at end of pickup, just proximal to capitellum, site of distal position of plate



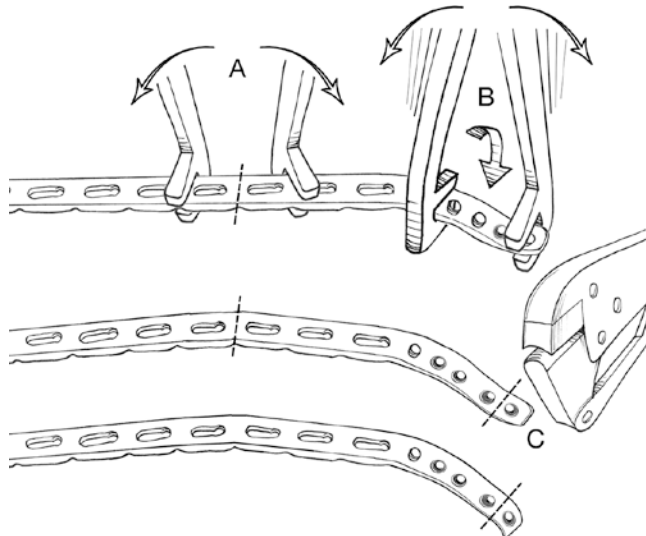
**Fig. 12.30** Capsule removed; note extended elbow and radial head position relative to capitellum

The final design did not incorporate the planned final distal contour (Fig. 12.31).



**Fig. 12.31** Plate positioned on humerus without plate bending

Thus, it is necessary to do some plate bending to attain proper distal seating (Fig. 12.32).



**Fig. 12.32** Diagrammatic representation of bends required to contour plate

Pre-stress bending is performed at the fracture site (Figs. 12.33 and 12.34).



**Fig. 12.33** Pre-stressing the plate



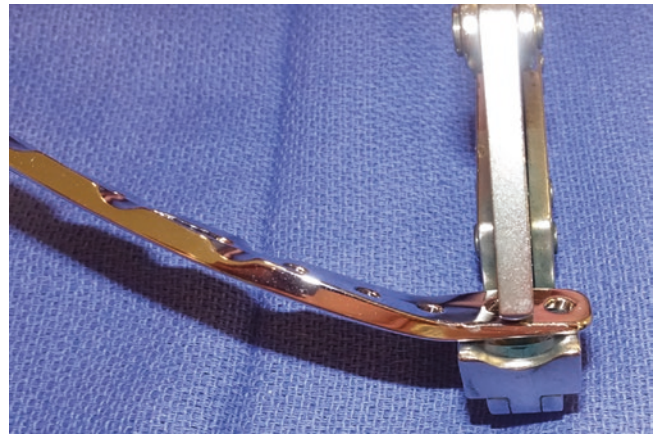
**Fig. 12.34** Pre-stressing the plate



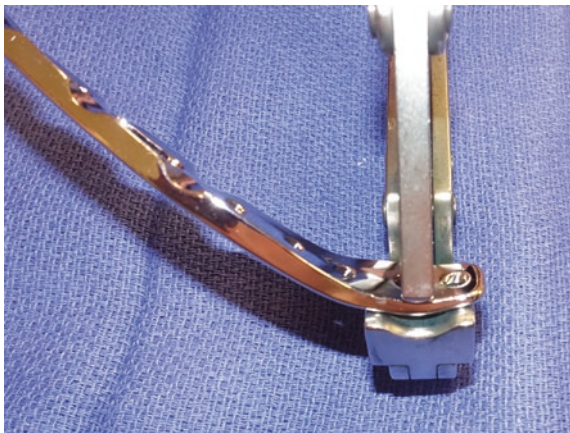
The distal bending requires a twist and bend, followed by a final cupping bend (Figs. 12.35, 12.36, 12.37, and 12.38).



**Fig. 12.35** Final distal twist and bend



**Fig. 12.36** Cupping at end between last two screw holes

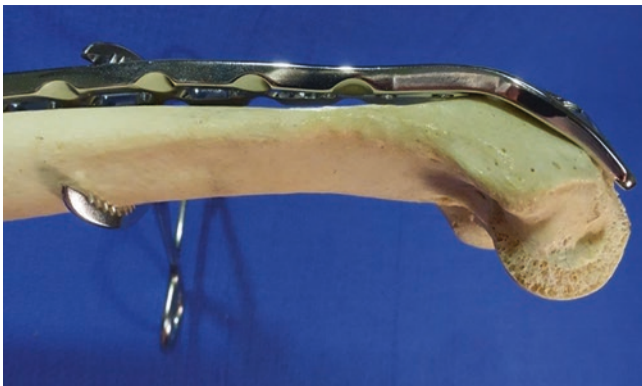


**Fig. 12.37** Cupping at end between last two screw holes



**Fig. 12.38** Final contour of plate

I use bending irons for the twist and bend, and handheld plate benders for the cupping (Figs. 12.39, 12.40, and 12.41).



**Fig. 12.39** Plate contoured and positioned on humerus



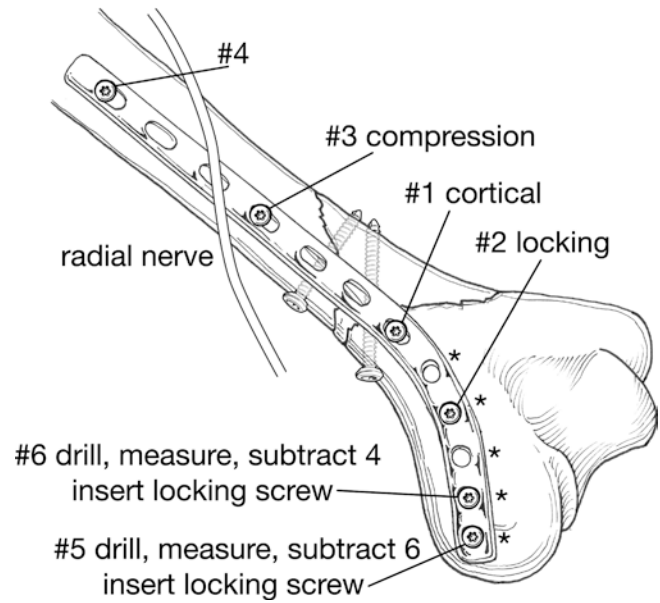
**Fig. 12.40** Plate contoured and positioned on humerus





**Fig. 12.41** Plate contoured and positioned on humerus

Definitive plating is performed after the humerus is provisionally stabilized with mini-fragment plates or lag screws (Fig. 12.42).



**Fig. 12.42** Suggested sequential screw option for initial fixation using the extra-articular plate

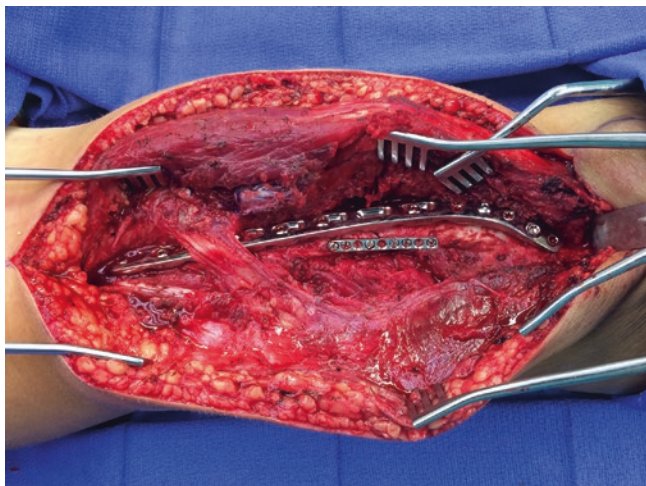
### 12.4.3 Drilling Bone and Screwing the Plate

The plate terminates at the distal cortical bone cartilage junction. I then insert a cortical screw in the distal fragment, followed by at least one locking screw to prevent plate rotation. The five distal locking-screw holes will accept cortical screws but will sit proud because the holes are not beveled to allow the screws to seat deeper. The plate positioning is done with the proximal portion of the plate aligned with the bone. I then

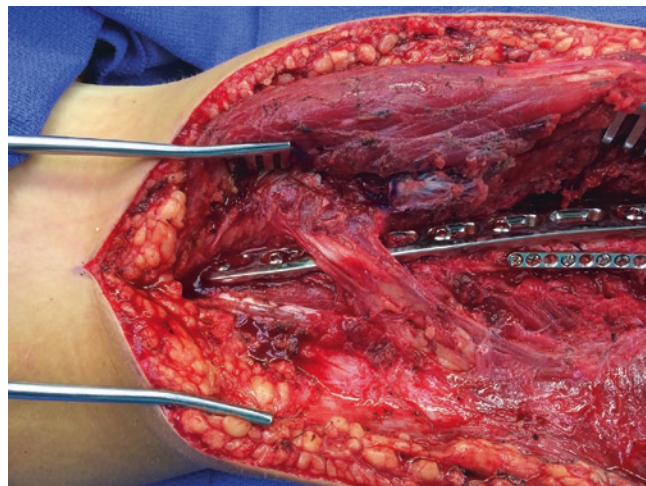
compress proximally. (Yes, you can do this even with provisional fixation.) The two distal locking screws are inserted with the following guidance: Drill the most distal screw hole through the guide to the subchondral bone, measure, and subtract 6 mm. (Typically, the screws will be 16–20 mm in length.) For the next most distal screw, drill, measure, and subtract 4 mm; the screw length will be 18–24 mm. Don't ask, just follow my lead (Figs. 12.43, 12.44, 12.45, 12.46, 12.47, 12.48, 12.49, 12.50, 12.51, 12.52, 12.53, and 12.54).



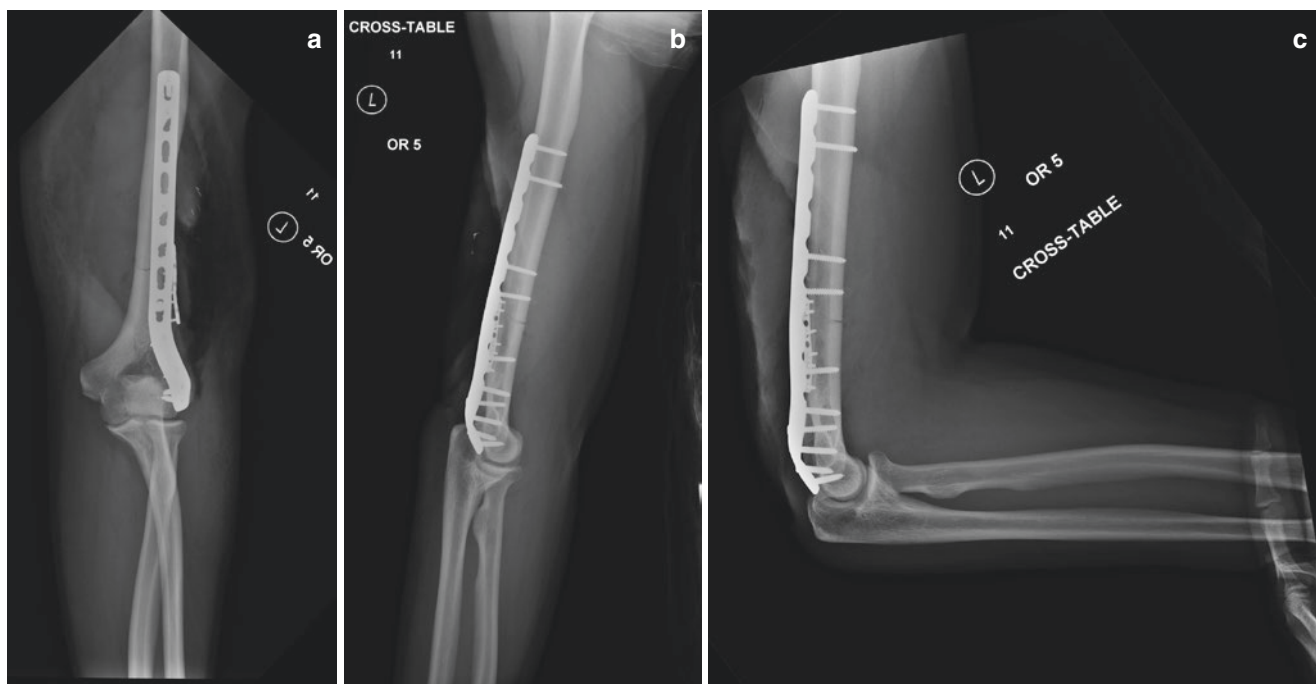
**Fig. 12.43** (a–c) Injury radiographs of left distal humerus supracondylar fracture. By measurement, this fracture just falls into the supracondylar group



**Fig. 12.44** Fixation of left humerus supracondylar fracture with mini-fragment plate for provisional fixation and distal position of plate

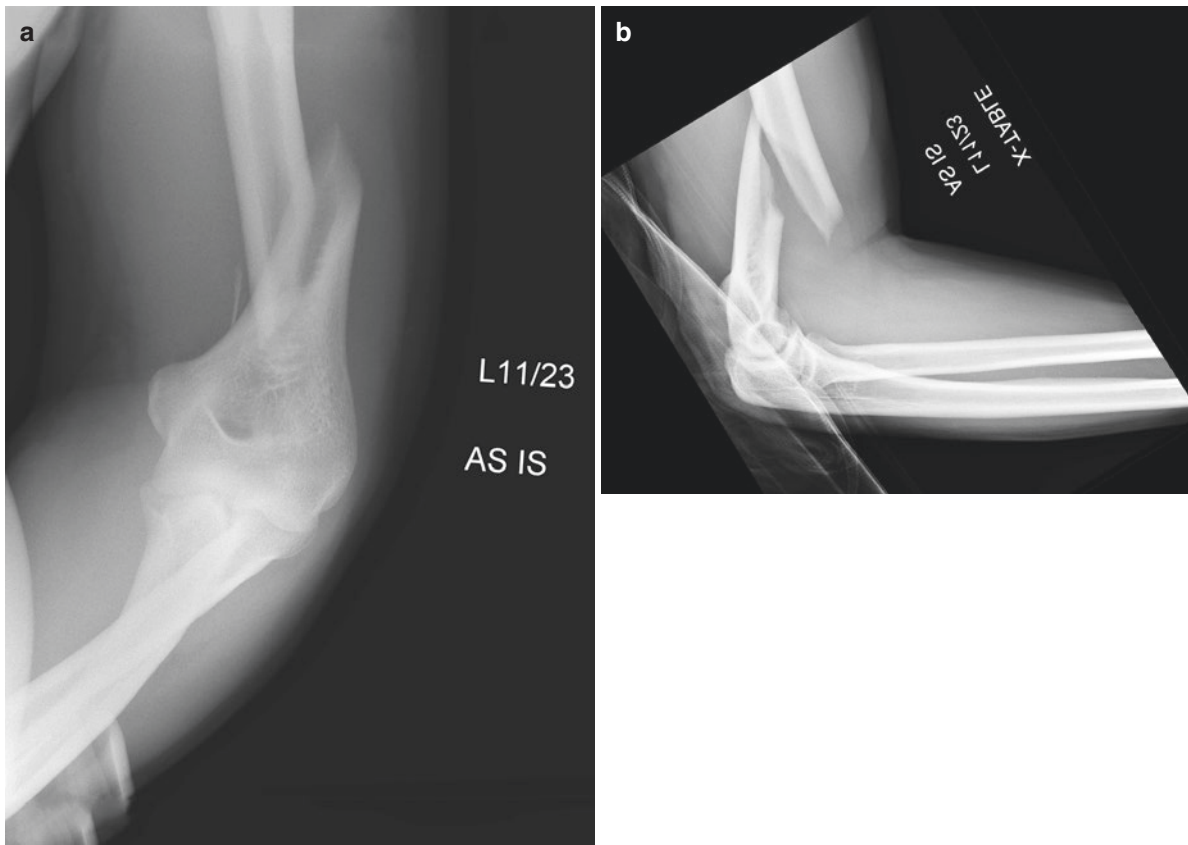


**Fig. 12.45** Proximal dissection demonstrating triceps fascia excision and en bloc elevation of radial nerve and profunda arterial system

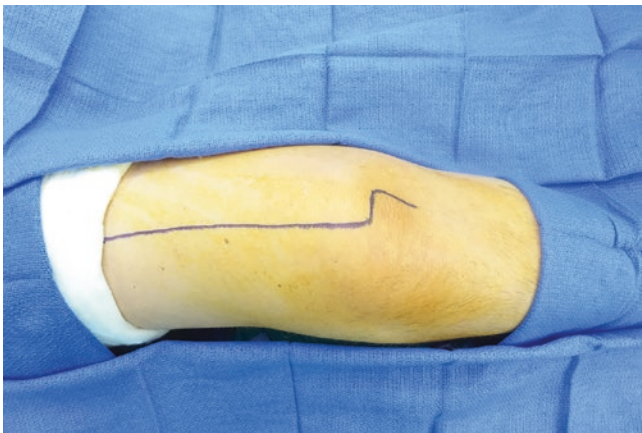


**Fig. 12.46** (a, b) Intraoperative radiographs demonstrating distal extent of plate on full extension. (c) Intraoperative radiographs with elbow in flexion

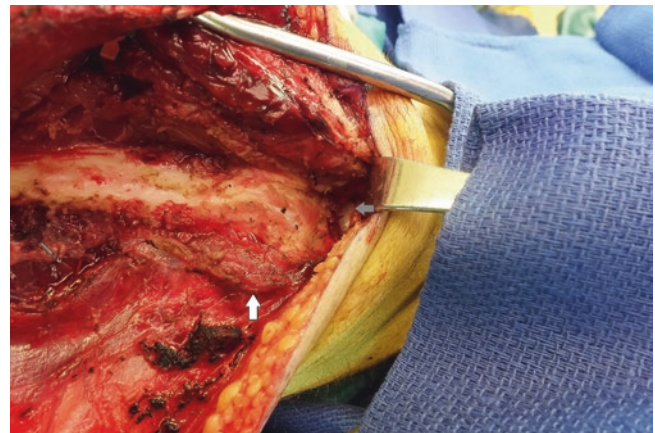




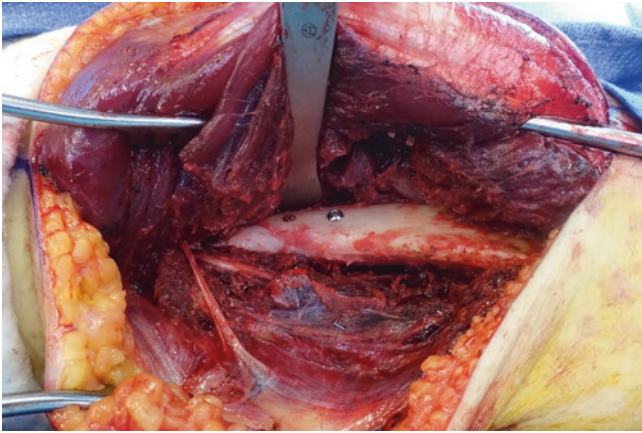
**Fig. 12.47** (a, b) Anteroposterior (AP)/lateral radiographs of left distal humerus supracondylar fracture. The patient elected operative intervention



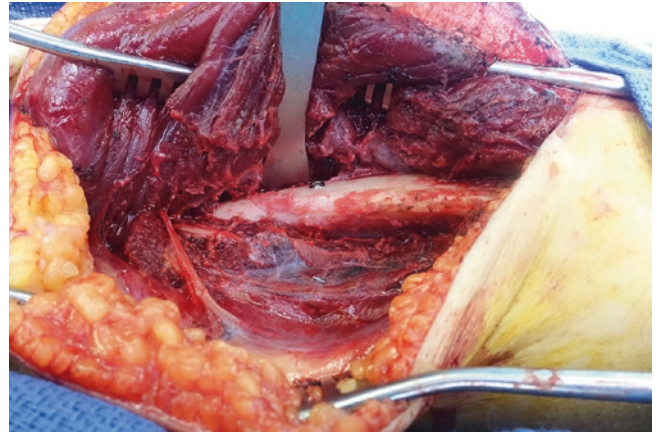
**Fig. 12.48** Posterior incision for supracondylar fracture; sterile tourniquet to the left



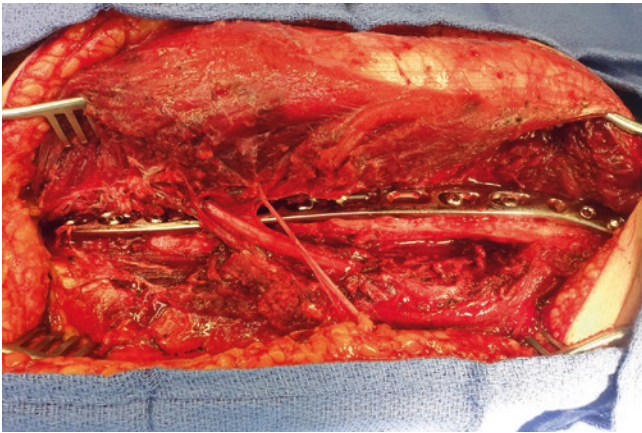
**Fig. 12.49** Distal half of incision with triceps medialized, demonstrating posterior radial collateral system (white arrow) and radial head (grey arrow)



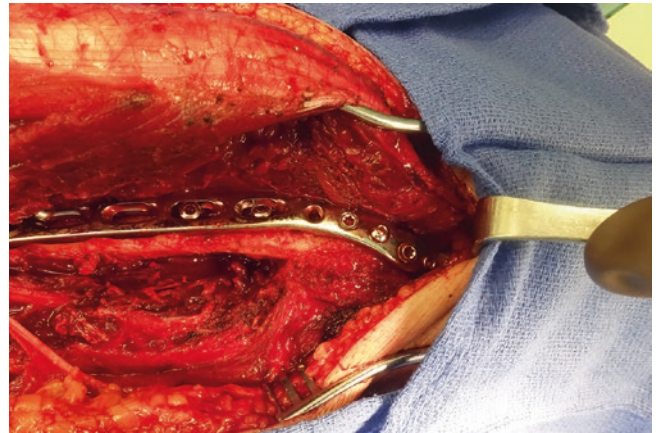
**Fig. 12.50** Provisional lag screw fixation following reduction, brachio-cutaneous branch dissected through triceps to allow proper triceps mobilization, using a 2.0-mm screw proximally and a 2.7-mm screw distally



**Fig. 12.51** Lateral projection of reduction

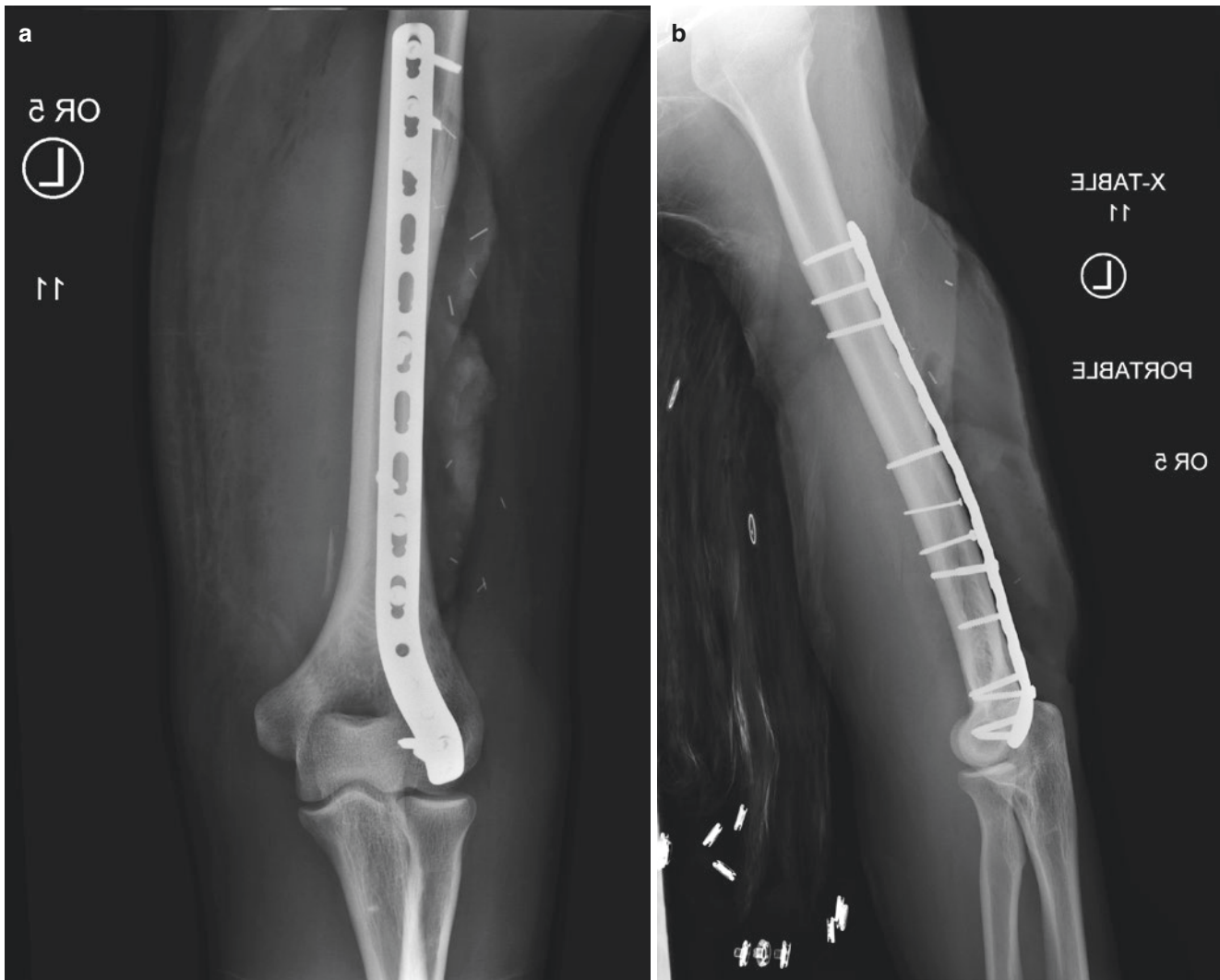


**Fig. 12.52** Definitive fixation with Synthes® extra-articular distal humerus plate



**Fig. 12.53** Distal extent of plate at the capsular synovial reflection proximal to the capitellum





**Fig. 12.54** (a) Intraoperative posteroanterior (P/A) radiograph demonstrating the distal extent of the plate. (b) Intraoperative lateral radiograph. Note the distal extent of the plate and shaft screw through the plate in lag fashion

#### 12.4.4 Postoperative Activity

The initial spirit of the plate was to allow weight-bearing as tolerated, which is my general rule for ORIF of humeral shaft fractures. Early on, however, a couple of patients bent the plate, so I now recommend no weight-bearing for 6 weeks. For activities of daily living, I recommend unrestricted range of motion and use.

#### References

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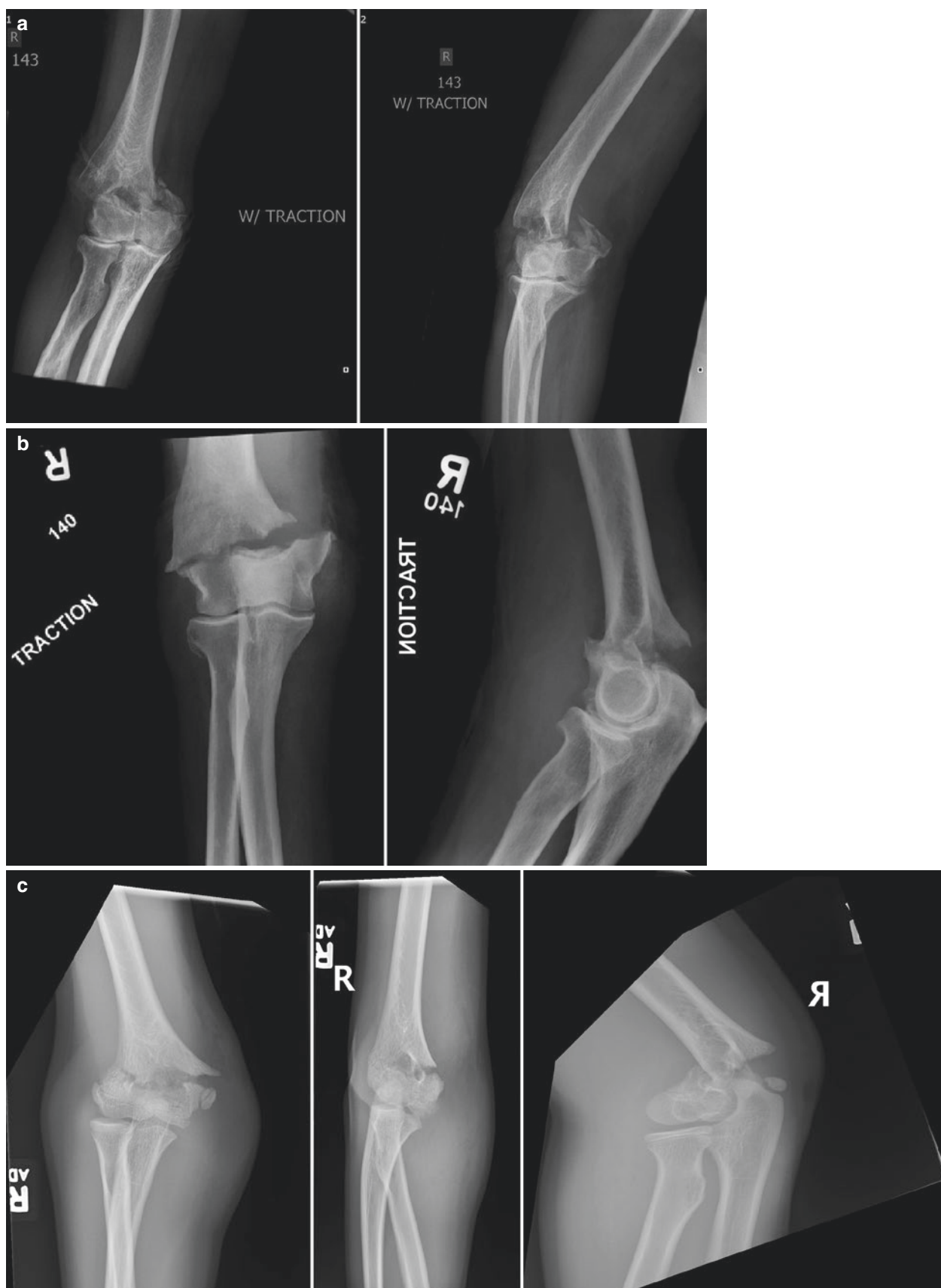


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### 13.1 Transcondylar Fractures in Older and Younger Populations

A close cousin to the supracondylar fracture is the transcondylar fracture. The transcondylar fracture tends to occur in slightly more mature (code for older) individuals and tends

to be more transverse, through the level at or just proximal to the epicondyles, and tends to have a flat pattern [1], as seen in Figs. 13.1a, b. Figure 13.1c, however, illustrates a transcondylar fracture in a younger patient.



**Fig. 13.1** (a) Radio graphs of transcondylar fracture in traction, demonstrating transverse pattern in a patient age 72. (b) Radiographs of transcondylar fracture in traction demonstrating transverse pattern in

patient age 77. (c) Injury radiographs of adolescent with transcondylar distal humeral fracture

## 13.2 Nonoperative Treatment

Nonoperative treatment can be successful, as seen in Fig. 13.2, but problems can arise. First, there is the potential for the fracture to be intracapsular and bathed with

synovial fluid, impeding fracture healing. Next, there is the potential for hemarthrosis, which can ultimately lead to capsular contracture and fibrosis, decreasing normal capsuloligamentous compliance.



**Fig. 13.2** (a) Injury radiographs. (b) 3-month radiographs with concern for potential nonunion. (c) Final radiographs at 6 months; the patient was pain-free with 145 degrees of elbow range of motion





**Fig. 13.2** (continued)

When motion is initiated, the stiff elbow concentrates attempted motion at the fracture, which can lead to nonunion or pseudoarthrosis (Fig. 13.3).



**Fig. 13.3** Nonunion of left distal humeral transcondylar fracture

Finally, motion and subsequent fracture healing can be associated with callus formation in the coronoid and olecranon fossae, impeding flexion and extension. Fixation obviates some of these problems by allowing early range of

motion, whereas nonoperative treatment is usually associated with some degree of immobilization, which leads to the problems noted above.

### 13.3 Surgical Treatment Options

Surgical options include open reduction and internal fixation (ORIF) via a posterior paratricipital approach, generally without olecranon osteotomy. The other option is to perform medial and lateral approaches. The patient positioning and draping will be predicated upon the approach utilized. If the paratricipital approach is performed, the patient is positioned laterally with a sterile tourniquet. (see Chap. 10 for prepping

and draping.) The medial and lateral approaches are performed with the patient supine, also with a sterile tourniquet. (see Chap. 15 for prepping and draping.) The paratricipital skin incision is performed in a step-cut fashion. The medial approach incision is just posterior to the epicondyle, with attention to the medial antebrachial cutaneous nerve branches. I visualize but do not skeletonize the ulnar nerve. The lateral incision is slightly posterior to the lateral epicondyle (Fig. 13.4).



**Fig. 13.4** (a) Incision options for transcondylar fracture of the left arm, demonstrating the posterior step-cut incision and medial and lateral incisions. (b) Lateral incision slightly posterior to lateral epicondyle. (c) Medial incision slightly posterior to medial epicondyle. (d)

Posterior incision with paratricipital approach; the ulnar nerve is seen at top of photo. (e) Lateral approach with pickups at capitellum synovial reflection

### 13.3.1 Use of Column Screws, Plates, and Dual Plates for Fixation

The fixation utilized for these fractures encompasses column screws, column screws with plates, or dual plates (Figs. 13.5, 13.6, 13.7, and 13.8) [2].

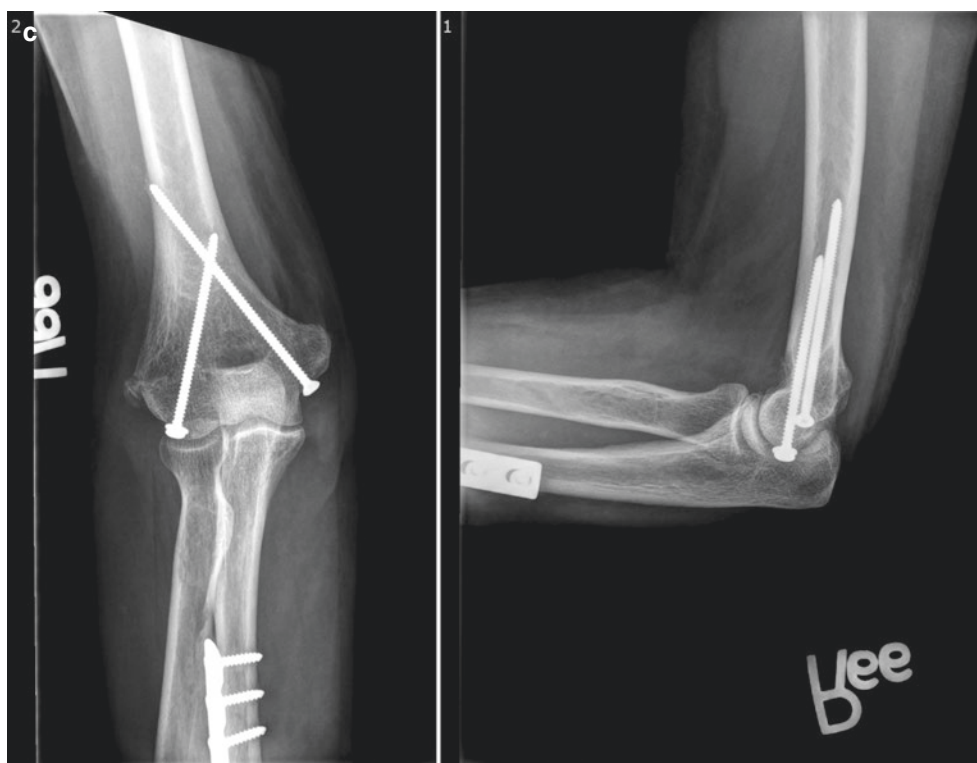
**Fig. 13.5** (a) Injury radiographs of left distal humeral transcondylar fracture. (b) Radiographs following column screw fixation. Note broken guide wire



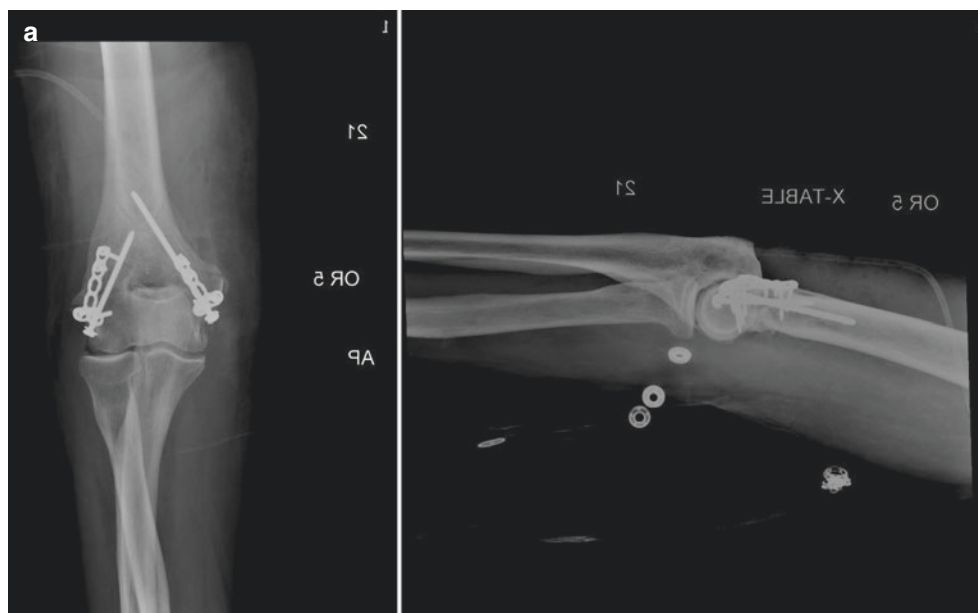




**Fig. 13.6** (a) Injury radiographs of right distal humeral transcondylar fracture. (b) Forearm radiographs reflecting associated ulnar fracture. (c) Radiographs following column screw fixation



**Fig. 13.6** (continued)



**Fig. 13.7** (a) Intraoperative radiographs following open reduction and internal fixation (ORIF) using column screws and plates, in the same case as Fig. 13.1b. The lateral radiograph reflects full extension not blocked by a plate. (b) Follow-up radiographs

**Fig. 13.7** (continued)**Fig. 13.8** Radiographs following ORIF with dual posterior plates, in the same case as Fig. 13.1c



More proximal fractures generally are slightly oblique, and dual plates are used, with a posterior paratricipital approach (Fig. 13.9).

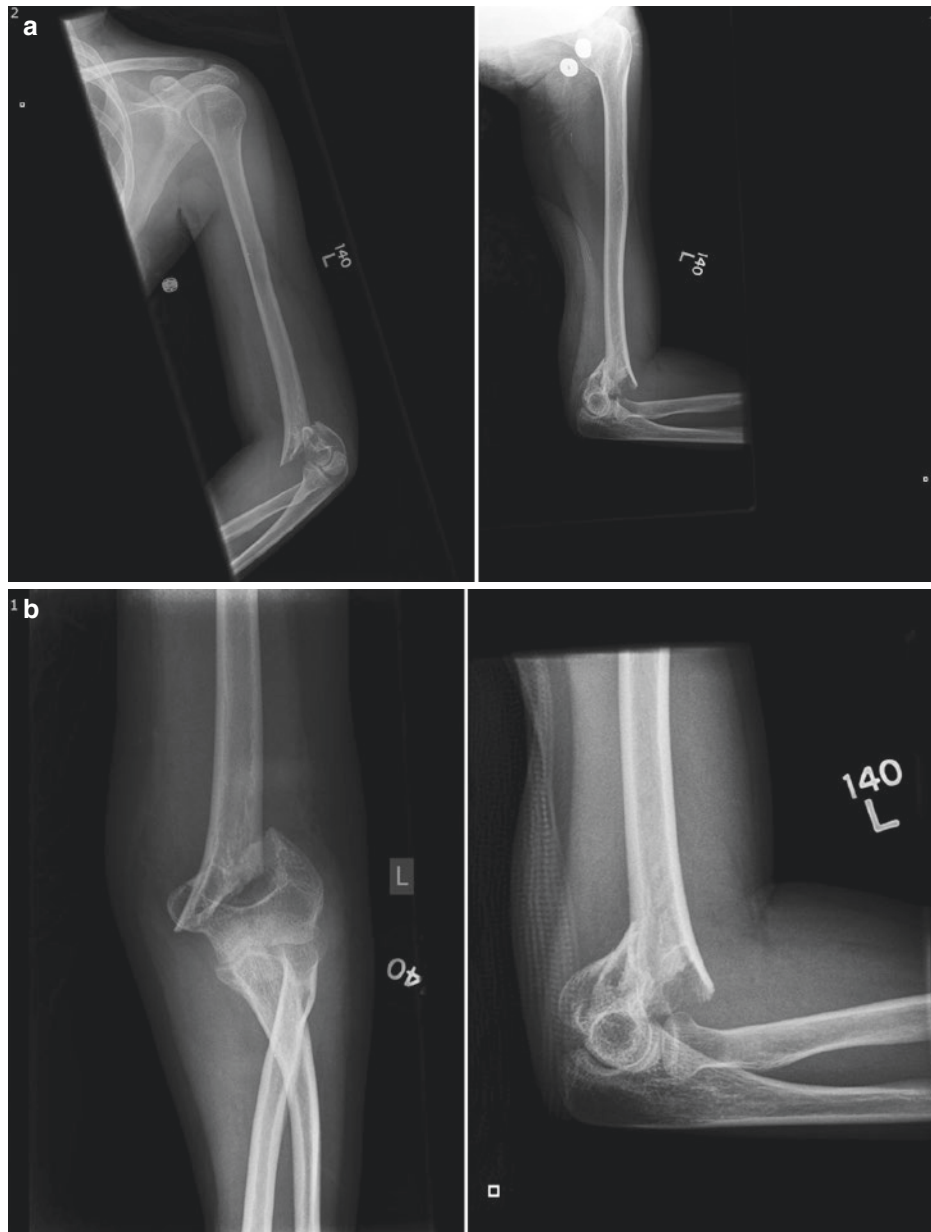
**Fig. 13.9** (a) Traction radiograph; the obliquity of this transcondylar fracture complicates the use of column screws alone because of potential shearing and displacement without associated buttressing. (b) Orthogonal plate fixation using a paratricipital approach without olecranon osteotomy



The obliquity of the fracture needs to be respected, as extension injuries shear posteriorly and plates are placed in an anti-glide or buttress mode posteriorly, with the patient generally in the lateral position (Figs. 13.10 and 13.11).

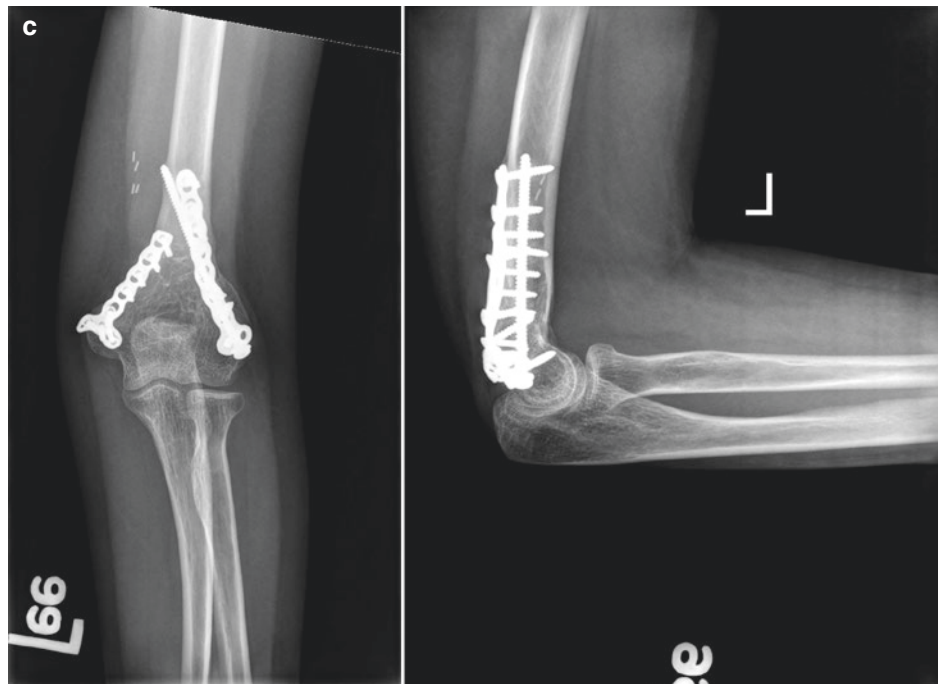
**Fig. 13.10** (a) Radiographs of right distal humeral fracture in splint following transfer from an outside facility. Note the oblique nature of the fracture on the lateral radiograph. (b) Plates positioned to resist shear and displacement





**Fig. 13.11** (a) Injury radiographs of left distal humeral transcondylar fracture. (b) Dedicated elbow radiographs. (c) Radiographs at time of discharge, with posterior plates and lateral column screw



**Fig. 13.11** (continued)

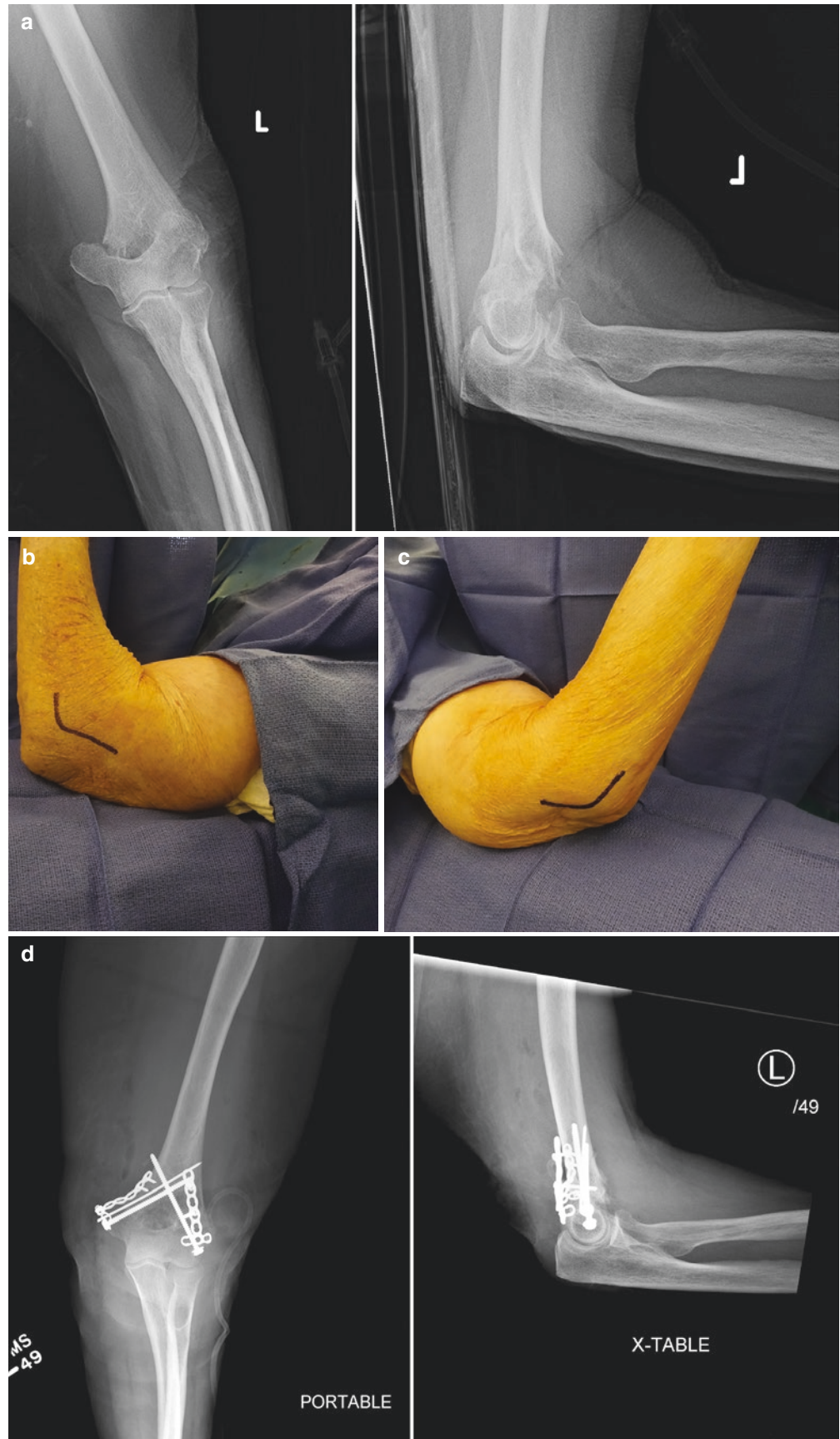
The supine position is used for the medial and lateral incisions, particularly when there is a flexion shear orientation; thus, the plates are placed in an anti-shear position anteriorly (Fig. 13.12).

**Fig. 13.12** (a) Injury radiographs of right distal humeral transcondylar fracture. (b) Radiographs following fixation, including anterior plates to resist anterior shear found during approach



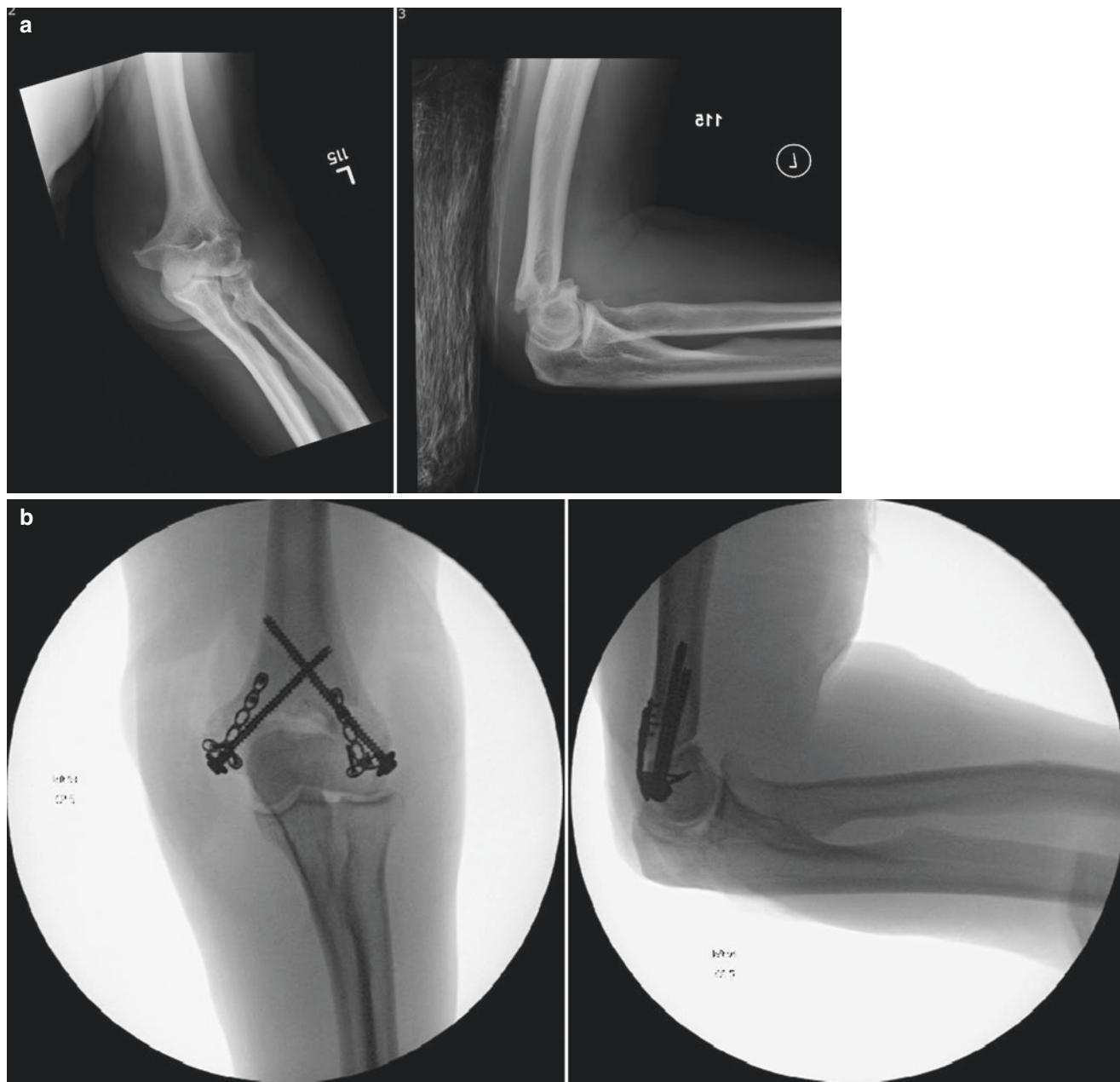
Medial and lateral incisions also can be used for posterior plate fixation if medical or other conditions preclude lateral positioning, as in Fig. 13.13.

**Fig. 13.13** (a) Injury radiographs of left distal humeral transcondylar fracture. (b) Lateral incision for distal humeral approach. (c) Medial incision for distal humeral approach. (d) Radiographs following ORIF





Make sure you get the shear component appreciated, as improper plate positioning can aggravate the displacement (Fig. 13.14).



**Fig. 13.14** (a) Injury radiographs of left distal humeral transcondylar fracture. (b) Intraoperative radiographs with posterior fixation; note obliquity of fracture with potential for anterior displacement. (c) Follow-up radiographs with anterior displacement. (d) Further follow-

up, with anterior callus present and obstruction of coronoid fossa. (e) Radiographs following capsulectomy, contouring and recreating the fossa to remove the block from the callus and hardware removal. (In case you were wondering, this is my case)

**Fig. 13.14** (continued)

### 13.3.2 Fixation Steps

Figure 13.15 illustrates the steps generally used in fixation, using medial and lateral approaches. I begin with the lateral exposure, then the medial exposure, then reduce laterally and

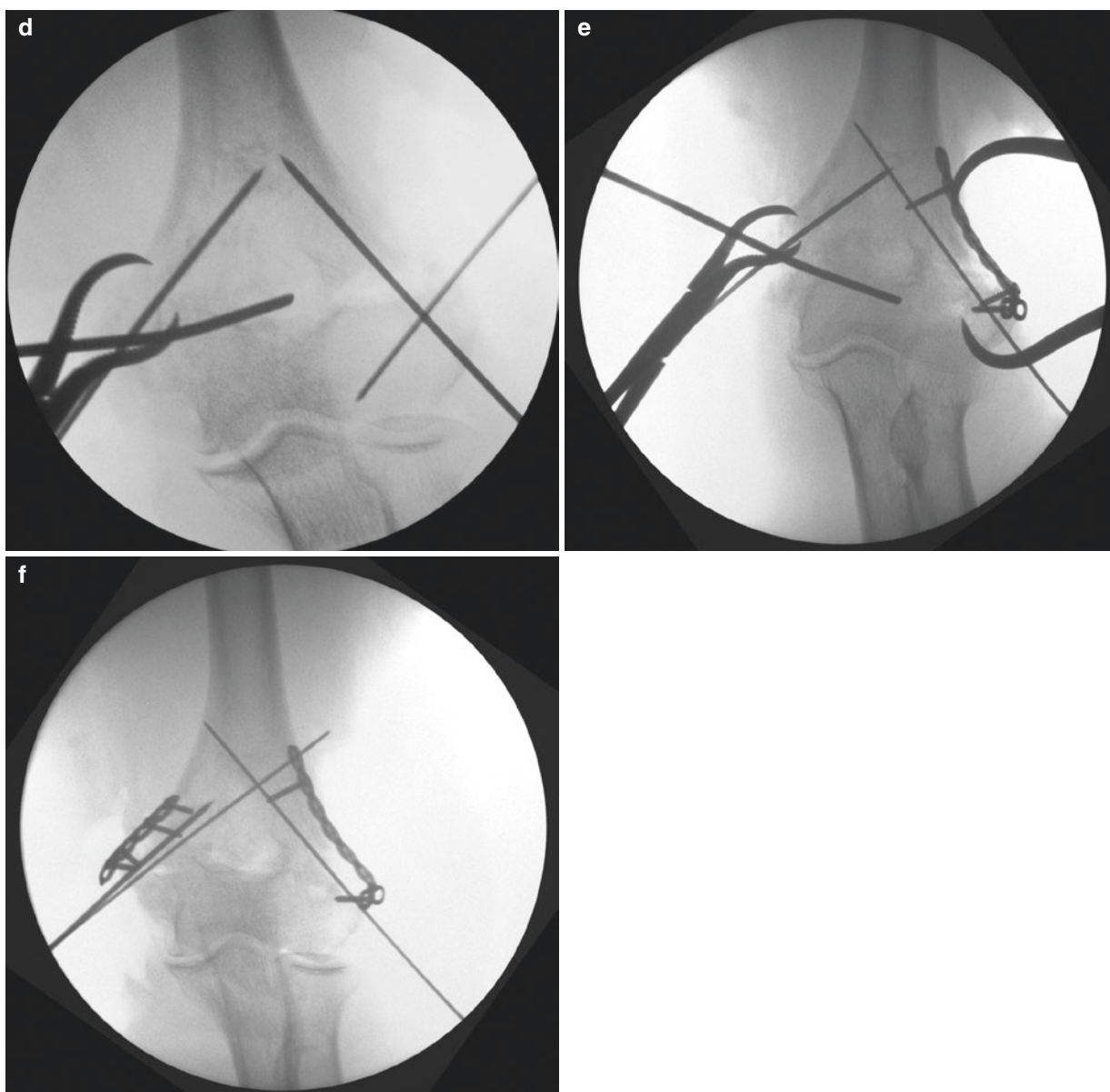
K-wire, then reduce medially and K-wire. I call this technique *successive approximations*. Then the more compressible column (*i.e.*, the less comminuted column) undergoes screw or plate fixation. In the case shown, plates and column screws were used.



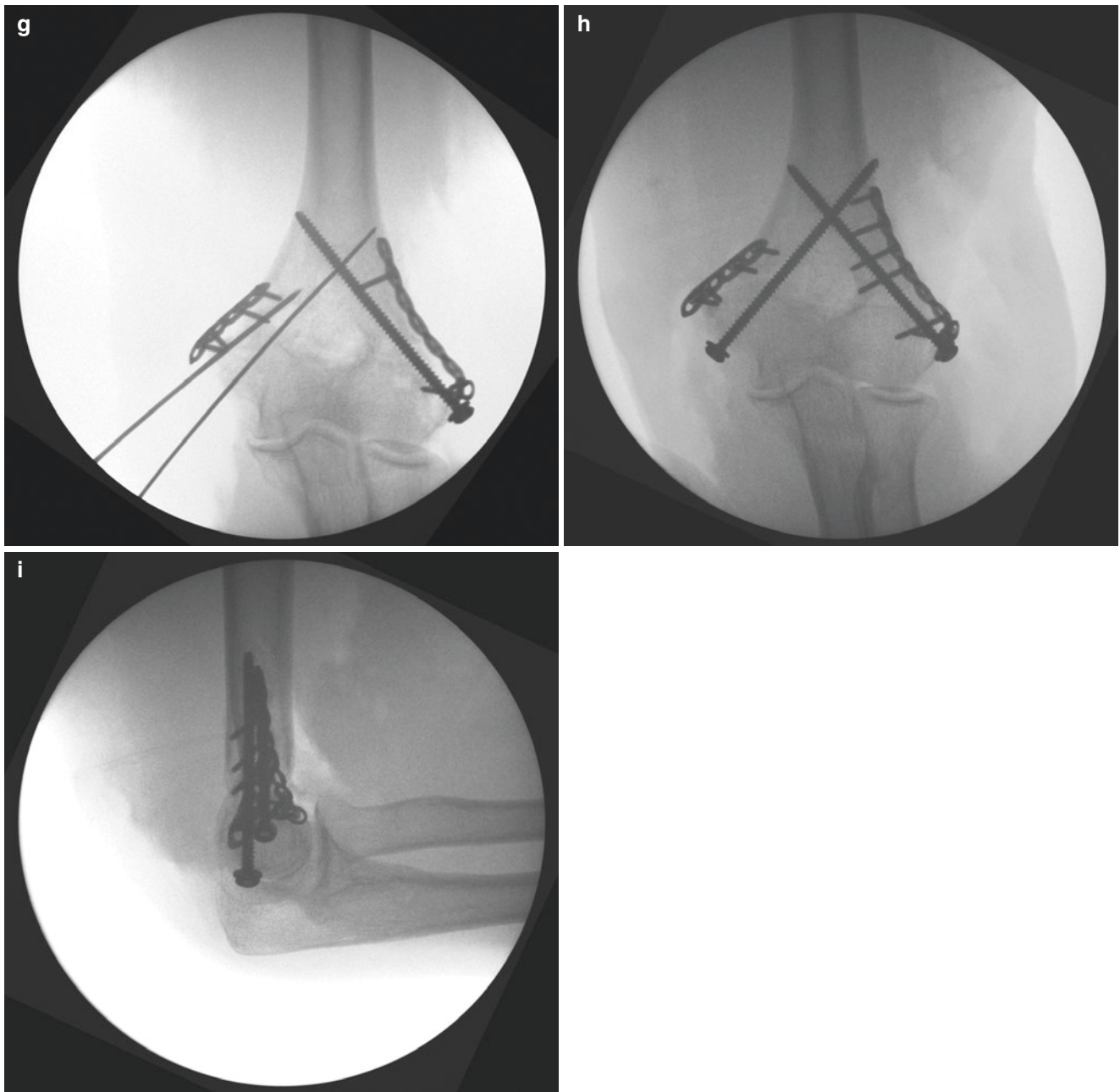
**Fig. 13.15** (a) Radiographs of left humerus, demonstrating proximal and distal humeral fractures. Supine position was selected to allow proximal humeral fixation anteriorly and medial and lateral approaches to the elbow. (b, Dedicated elbow radiographs. (c) Radiographs following ORIF of the proximal humeral fracture performed before the elbow fixation, with both shoulder and elbow approaches performed simulta-

neously. (d) Sequential steps in fixation of the transcondylar fracture, beginning with a threaded Steinmann pin as a joystick and provisional Kirschner wire (K-wire) fixation. (e) Lateral plate fixation. (f) Medial plate fixation. (g) Lateral column screw. (h) Medial column screw. (i) Lateral radiograph. (j) Radiographs at time of discharge

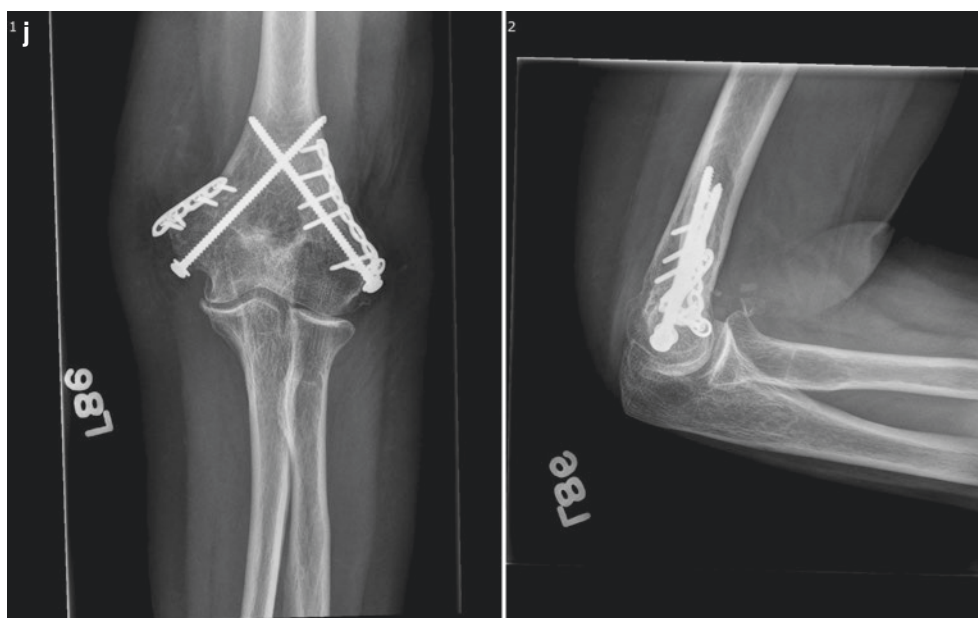




**Fig. 13.15** (continued)



**Fig. 13.15** (continued)



**Fig. 13.15** (continued)

### 13.3.3 Ulnar Nerve Concerns with Use of Column Screws Only

If only column screws are used, I rarely perform purely percutaneous fixation (particularly medially), because of concern about hurting the ulnar nerve. The medial and lateral incisions and approaches are used for open screw placement. I try to use a cannulated screw system, but some systems do not have screws that are long enough; longer, solid screws are required. I will still set up the fixation using the cannulated system and guide wires, measure, drill, and sometimes tap. I then remove the guide wire and insert the solid, non-cannulated screw.

### References

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### 14.1 Establishing Guidelines for Treating a T-Intercondylar Fracture

The end of the trauma rotation draws near and the almost annoyingly enthusiastic resident has finally gotten a T-intercondylar fracture. After setting the patient up for surgery, and while scrubbing our hands, I hit the resident with the “sink test.” After much stumbling and bumbling, the resident gets to some answers: An approach needs to be determined and then performed. Something needs to be done with the nerve, and fixation needs to be carried out on the joint, with the joint being stabilized to the humerus shaft. We go over some guidelines for the procedure:

1. Prone position
2. Tourniquet
3. Incision with a transverse step-cut at the elbow
4. Ulnar nerve retracted
5. Olecranon osteotomy in a V fashion
6. Joint reduction fixation

7. Joint fixation to the shaft
8. Osteotomy fixation with a screw
9. Ulnar nerve occasionally transposed, but generally replaced in its bed
10. Early range of motion

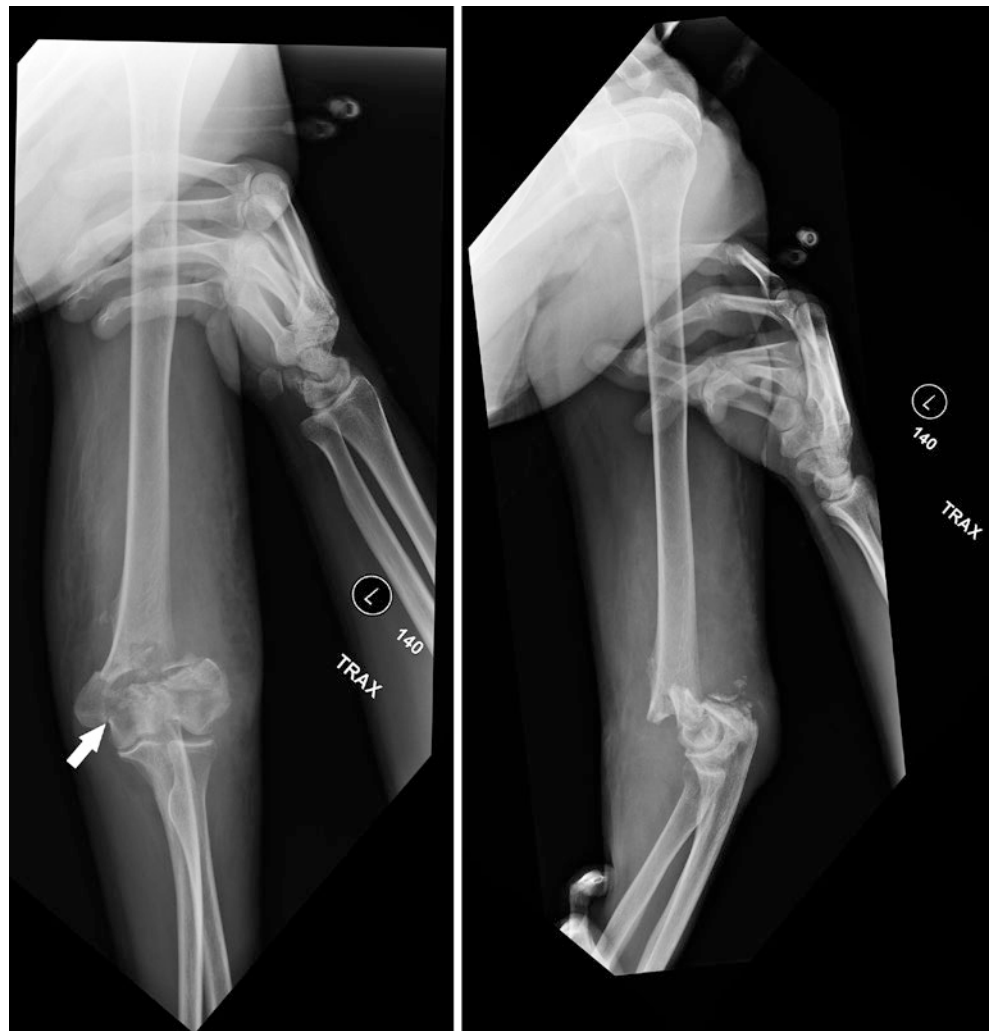
Now, here’s a test for you: Where do these guidelines come from? Surprisingly, they were put forth by Dr. Cassebaum in the *American Journal of Surgery* in 1952 and reiterated in 1969 [1, 2]. (Perhaps you thought a particular Swiss fixation group laid out these principles?)

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### 14.2 Modifications and Additions to the Guidelines

Rarely do I request a CT scan of the distal humerus. I prefer traction films, which generally elucidate the number of fracture fragments and the potential for the fixation with or without an osteotomy (Figs. 14.1 and 14.2).

**Fig. 14.1** Injury radiographs (from an outside hospital) of left distal humerus fractures



**Fig. 14.2** Traction radiographs demonstrating fracture of the medial epicondyle at the trochlea (arrow)

Based on the plain X-rays and traction X-rays, you should have enough information to decide whether to surgically stabilize the fracture. As for the osteotomy, you are going to be looking at fracture fragments, and I have seen very few times that a CT scan has imparted any useful information.

My approach to the distal humeral T-intercondylar fracture is very similar to Cassebaum's guidelines, with a few additions and modifications. This chapter will go through the

treatment guidelines in a step-wise fashion, and at each step verify or reference scenarios to consider.

#### 14.2.1 Patient Positioning and Tourniquet

The patient is positioned in a lateral position and not prone. The patient's arm will ultimately be placed on a padded Mayo, as opposed to a bump (Figs. 14.3 and 14.4).



**Fig. 14.3** Lateral position with arm on Mayo



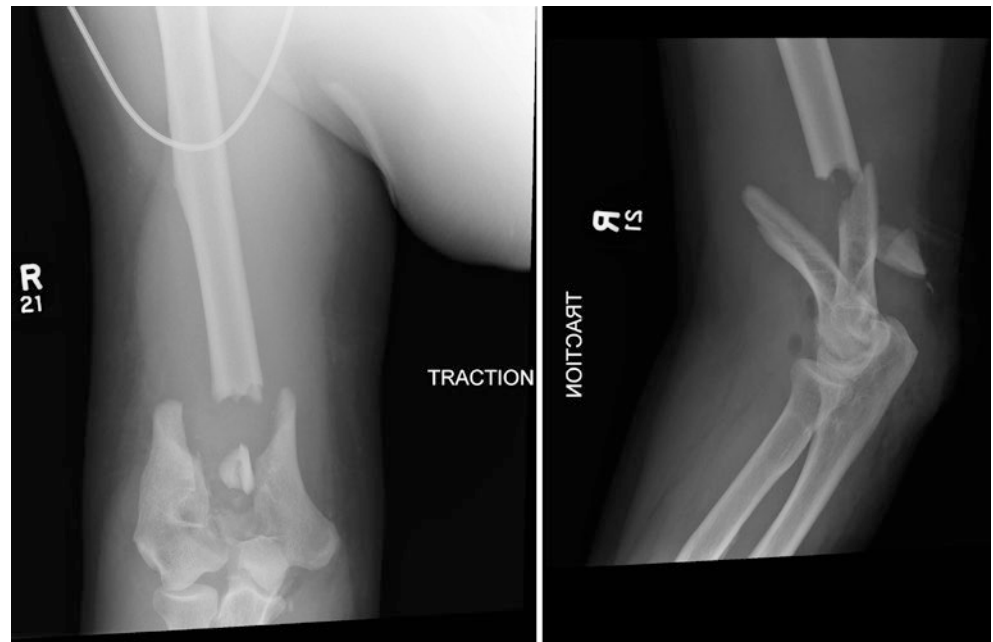
**Fig. 14.4** Arm resting over a bump

There are references to placing the arm on a bump and allowing the arm to hang over with the hand dependent. I do not like this, for a number of reasons. One is that the hand dependency can result in edema, particularly over a 3- to 5-h oper-

ation. Sterility is also a concern when the hand is in a dependent position. I also want to facilitate pre-positioning, with the arm extended (Figs. 14.5 and 14.6).



**Fig. 14.5** Traction radiographs of right distal humerus fracture



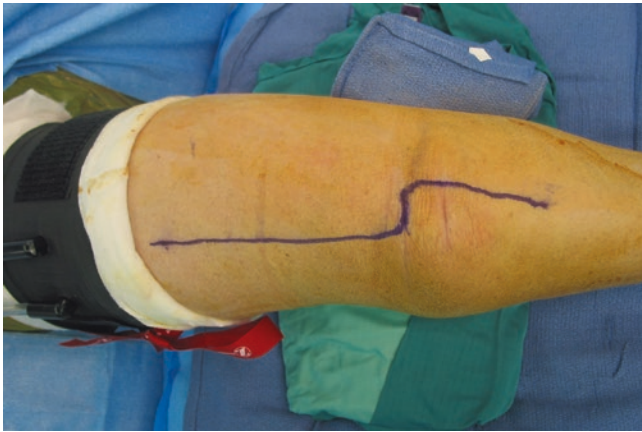
**Fig. 14.6** Intraoperative radiographs demonstrating in extension that the lateral plate is not impinging on the radial head (arrow)



If a lateral column plate is to be utilized with the arm in extension, there is an internal control keeping the placement of the plate from being too distal, which would result in blocking elbow extension: the fixation occurs when the arm is extended. A slight downside to the arm position in

extension is that the fracture will have a very slight tendency to apex anteriorly with the arm extended, and the lateral plating will need to be adjusted with a very slight over-contour to the plate to correct for the extended distal fragment.

I suspend the arm for the prepping and draping, which also includes the appropriate axillary roll positioning and beanbag. (see Chap. 10 for prepping and draping.) I like to apply a sterile pneumatic tourniquet, as opposed to a roll-up tourniquet, because there is a concern about secondary injury with telescoping of the fracture, although (depending on the proximal nature of the fracture) a roll-up tourniquet is nice because you can get a more proximal visualization and dissection without having to remove it.



**Fig. 14.7** Clinical example of incision outlined for approach to left distal humerus

The way to remember this is to follow the nerves, particularly the radial nerve proximally and the ulnar nerve distally. I place a small bump beneath the elbow, as this allows the

### 14.2.2 Incision

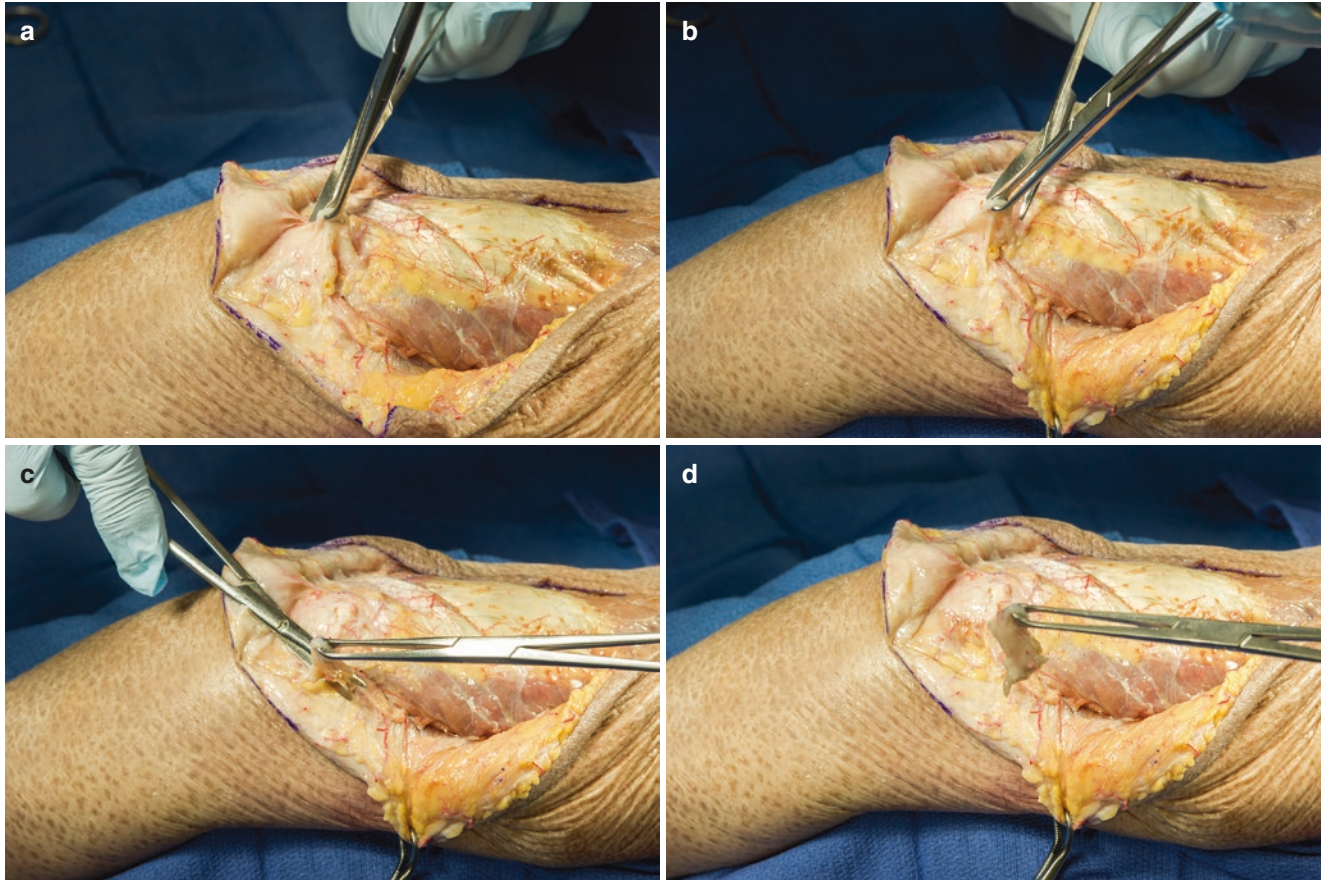
Once the patient is prepped and draped, the incision is outlined. I utilize a proximal longitudinal incision laterally, then incise across the tip of the olecranon, and distal and medially (Figs. 14.7 and 14.8).



**Fig. 14.8** Incision performed on right arm: shoulder to right hand to left; radial side up, medial down

skin to be slightly tensioned when making the incision. The arm is elevated and exsanguinated, and the tourniquet is inflated.

The skin is incised, and almost invariably a bursa needs to be excised (Fig. 14.9).



**Fig. 14.9** (a–d) Olecranon bursectomy performed

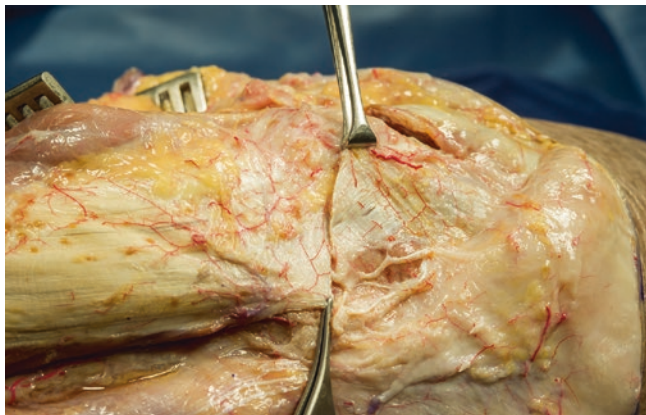
The skin flaps are elevated over the triceps with an incision of the triceps fascia. Distally, the flaps are elevated over

the flexor carpi ulnaris (FCU), the extensor carpi ulnaris (ECU), and the anconeus.

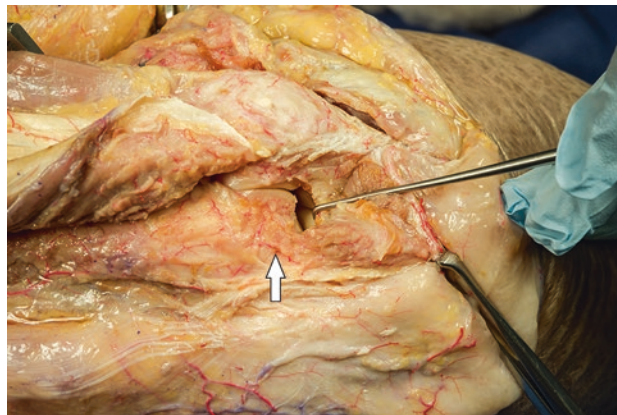


### 14.2.3 Dissection

Laterally, there will be a bare area at the posterior aspect of the lateral column and the condyle where the middle collateral vessel is located (Figs. 14.10 and 14.11).



**Fig. 14.10** Lateral approach in interval between triceps and anconeus



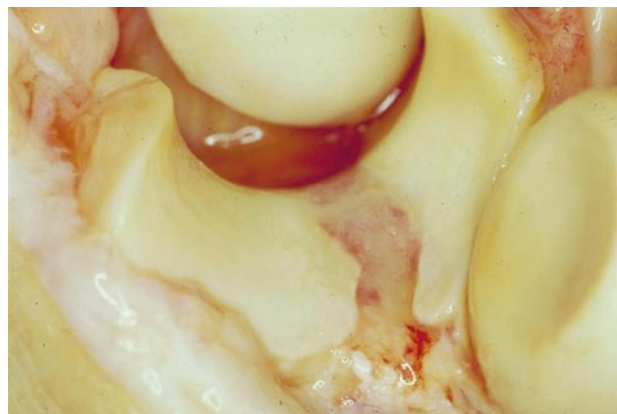
**Fig. 14.11** Triceps and anconeus reflected with middle radial collateral arterial arcade (*arrow*) on posterior aspect of lateral condyle; synovectomy performed to expose radial head, probe

A recent reference cites this vessel as the *medial collateral artery* [3]. I prefer naming it the *middle collateral* [4]. This is the vessel that cannot be compromised in a skeletally immature individual because of the risk for osteonecrosis of the capitellum. The intermuscular septum is followed laterally down to the posterior radial collateral artery and the posterior lateral cutaneous nerve of the forearm [5]. These are maintained laterally and used to guide the dissection proximally. Depending on the level of the fracture, they can be used to identify the radial nerve.

The dissection is carried distally between the anconeus and the triceps 4–5 cm distal from the tip of the olecranon process, acknowledging that this dissection will result in denervation of the anconeus, which will gain its innervation from the medial head of the triceps branch of the radial nerve. Care must be taken to avoid dissection into the annular ligament. A posterolateral capsulectomy is carried out, which will facilitate the visualization of the capitellum and the bare area between the olecranon and coronoid articular cartilage, where the olecranon osteotomy will ultimately be performed (Figs. 14.12 and 14.13).



**Fig. 14.12** Probe pointing to bare area between the olecranon and coronoid process, site of the apex of the osteotomy

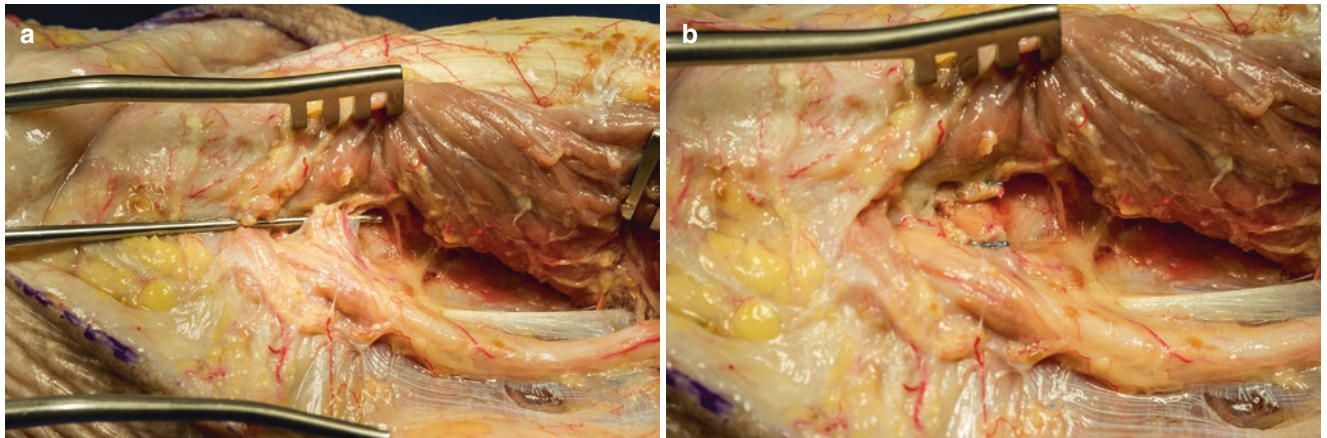
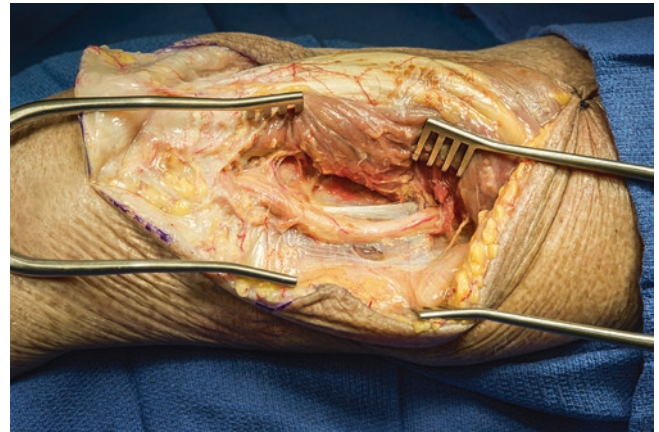


**Fig. 14.13** Bare area between the olecranon and coronoid process

### 14.2.4 Ulnar Nerve

The ulnar nerve is identified medially (Figs. 14.14 and 14.15).

**Fig. 14.14** Medial exposure of ulnar nerve and intermuscular septum (not arcade of Struthers)



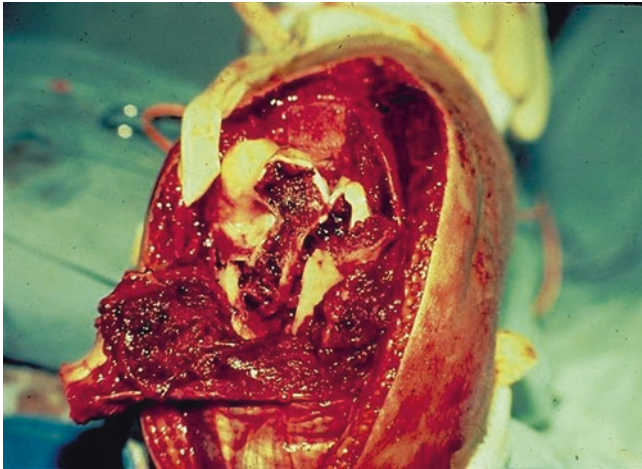
**Fig. 14.15** (a) Inferior ulnar collateral arterial branch to ulnar nerve lifted by a probe. Note the blood supply preserved with the ulnar nerve. No dissection on medial side of nerve assists in retraction of the nerve. (b) Inferior ulnar collateral arterial branch to ulnar nerve, divided

A self-retaining retractor is inserted. This will help with the localization of the ulnar nerve. The ulnar nerve is dissected away from the triceps with its longitudinal blood supply from the

superior ulnar collateral, inferior ulnar collateral, and posterior ulnar recurrent. There are watershed areas, but I still endeavor to preserve the longitudinal vascularity of the nerve [4, 6].



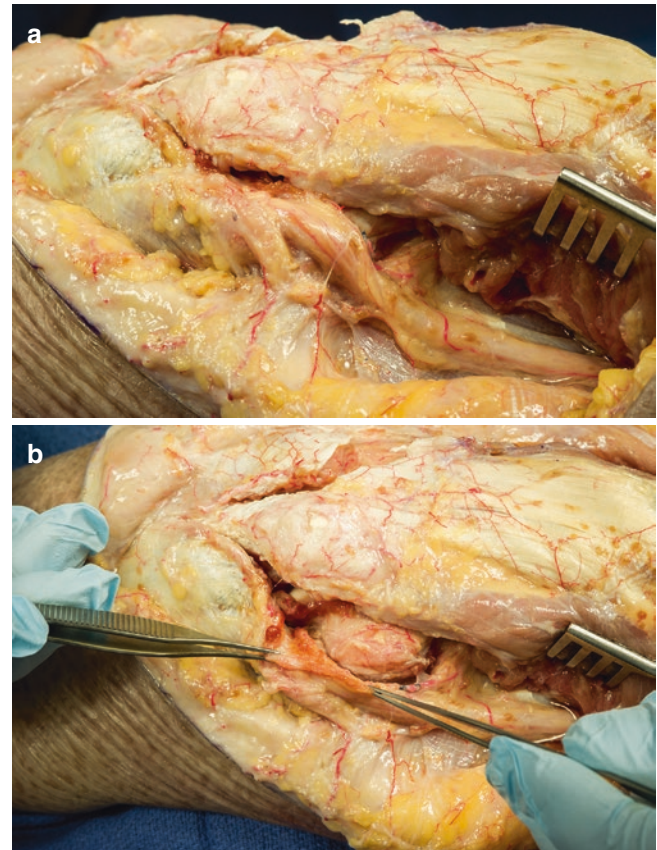
Perforators in the triceps are addressed with Ligaclips. I do not dissect on the medial side of the nerve, and I do not put vessel loops or Penrose drains around the nerve (Fig. 14.16).



**Fig. 14.16** Penrose around ulnar nerve—technique not to be utilized

I see no reason to circumferentially dissect, with Penroses or other devices placed around the nerve, as the devices tend to pull and tension the nerve. Also, by avoiding dissection on the medial side of the nerve, the nerve will be moved away from the triceps when the retractors are placed.

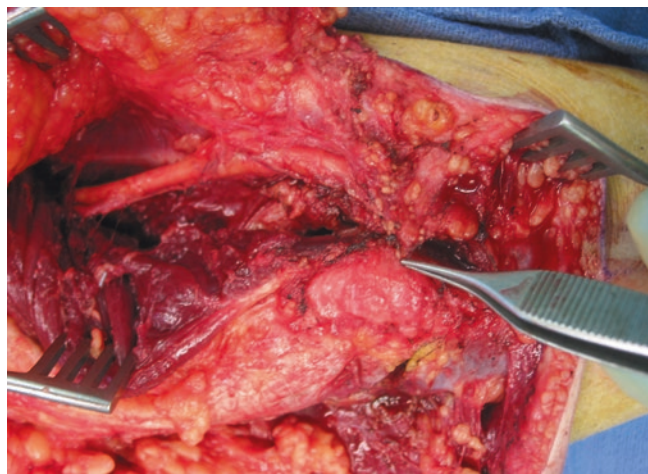
The dissection is carried down to the medial epicondyle, and a subperiosteal dissection is carried out in the cubital tunnel, elevating the ulnar nerve out of the cubital tunnel (Fig. 14.17).



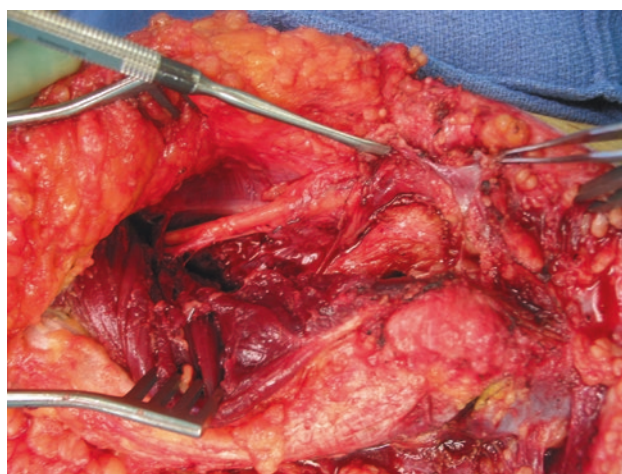
**Fig. 14.17** (a) Ulnar nerve subperiosteally elevated over medial epicondyle. (b) Ulnar nerve reflected over medial epicondyle with periosteal sleeve



The nerve will be provisionally positioned medial and anterior to the epicondyle, but will not be transposed (Figs. 14.18 and 14.19).



**Fig. 14.18** Clinical example of ulnar nerve elevated



**Fig. 14.19** Ulnar nerve reflected

Two aspects of this step are noteworthy. The first harkens back to the adage, “If you ever think you’ve come up with something new, it just means you can’t read German”—or any other European language. Years ago, after having come up with the above technique through numerous cases, I happened upon two articles by Krkovic *et al.* from Slovenia that referred to a subperiosteal elevation of the ulnar nerve [7, 8].

The second aspect worthy of note is the perceived need for anterior transposition of the ulnar nerve. Early in my training, I heard numerous chants for transposing the ulnar nerve anteriorly. I was told, “They said so.” I would then ask, “Who are *they*?” and nobody could really come up with a good answer about the origin of the recommendation for ulnar transposition. Searching the literature revealed that Schatzker and Tile [9] said in 1996 that the nerve is “transposed to the front.” Helfet and Schmeling [10] stated in 1993 that the ulnar nerve should be transposed anteriorly. In 1985, Jupiter *et al.* [11] noted that 21 patients had the nerve retracted, but only 9 were transposed. In 1994, Wang *et al.* [12] presented routine ulnar nerve transposition subcutaneously in 20 patients. Gupta and Khanchandani [13] reported in 2002 that no acute transposition was undertaken in 51 patients. A 2007 review by Doornberg *et al.* [14] noted no acute transposition in 30 patients.

Studies have compared results of ulnar nerve transposition to results without transposition. One study cited 16% postoperative nerve problems with transposition [15]. In this study, 47 patients (68%) underwent anterior transposition, and 22 patients (32%) had no transposition. Findings did not show that ulnar nerve neuropathy was decreased in the transposition group. Another study found that ulnar nerve neuritis was four times greater in cases with anterior transposition than in cases without transposition [16].

My belief is that the best transposition is submuscular. If any medial fragment still has soft tissue attached, it is very difficult to justify elevating attachments to transpose the nerve. Also, it is very difficult to transpose the nerve anteriorly and submuscularly with the patient in a lateral position. Finally, if a patient has had an anterior subcutaneous transposition and further surgery is needed, I have found that the nerve actually makes four right angles: one as the nerve comes up to the epicondyle, another coming over the flexor pronator mass, then back down the pronator mass, and finally into the forearm flexors. Talking to residents and fellows from other programs, I believe that the winds of change have blown back towards the position of no ulnar nerve transposition.

Once the ulnar nerve is mobilized out of the cubital tunnel, dissection is carried down to the coronoid without disruption of the medial collateral ligament (MCL) in preparation for either fixation or the olecranon osteotomy (Fig. 14.20).



**Fig. 14.20** Flexor carpi ulnaris elevation to expose medial ulnohumeral articulation with preservation of the medial collateral ligament

### 14.2.5 Osteotomy

I am frequently asked, “Do you always do an osteotomy?” Because I believe that patients rehabilitate better without an osteotomy, I prefer not to do them, but in my practice, the opportunity to perform an ORIF of the distal humerus fracture without an osteotomy is rare. Fractures that can be

repaired without an osteotomy are usually a noncomminuted T-fracture with fracture visualization that can be attained by the paratricipital approach. Frequently, the fracture exits lateral to the lateral trochlear ridge, or there are good keys in the supracondylar region to allow joint reduction using extra-articular keys (Figs. 14.21 and 14.22).

**Fig. 14.21** Injury radiographs of left distal humerus fracture

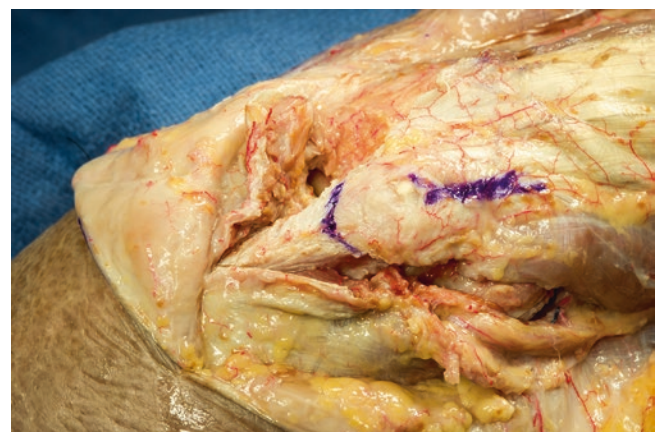


**Fig. 14.22** Postoperative splinting radiograph following open reduction internal fixation (ORIF) without osteotomy



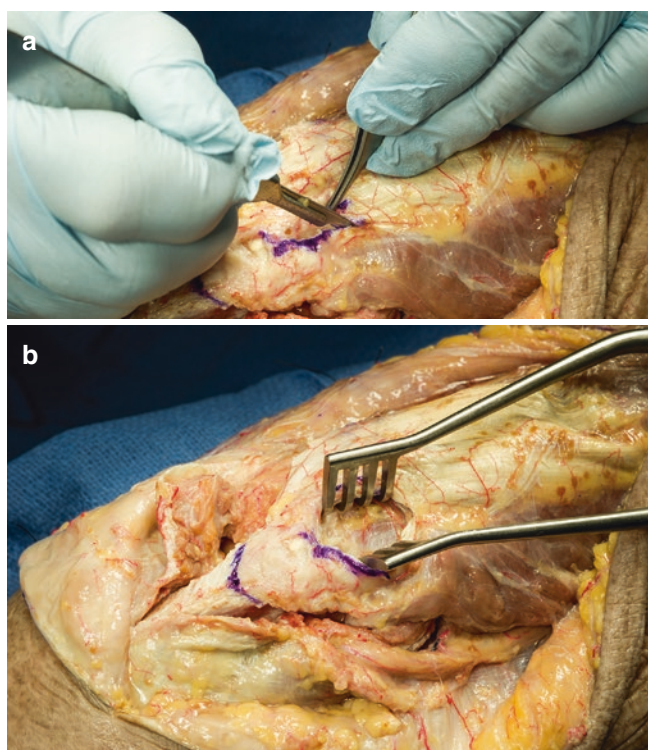
Without these favorable variables, the olecranon osteotomy is frequently utilized. The olecranon osteotomy is performed after the ulna is predrilled and tapped. I prefer to use a longitudinal screw with a tension band wire, even though there seems to be great enthusiasm for plate fixation. Reports by Henley *et al.* [17] and Cannada *et al.* [18] have reviewed the incidence of screw problems and found very low removal or complication rates.

My algorithm uses primarily a 6.5-mm screw. If I do not get adequate purchase or fixation, I use a 7.3-mm screw, then a Kirschner wire (K-wire) tension band. Only after these have been dismissed would I consider plating. The steps in the preparation include a split in the triceps and predrilling with a 3.2-mm drill bit (Figs. 14.23 and 14.24).



**Fig. 14.23** Osteotomy and triceps incision outlined

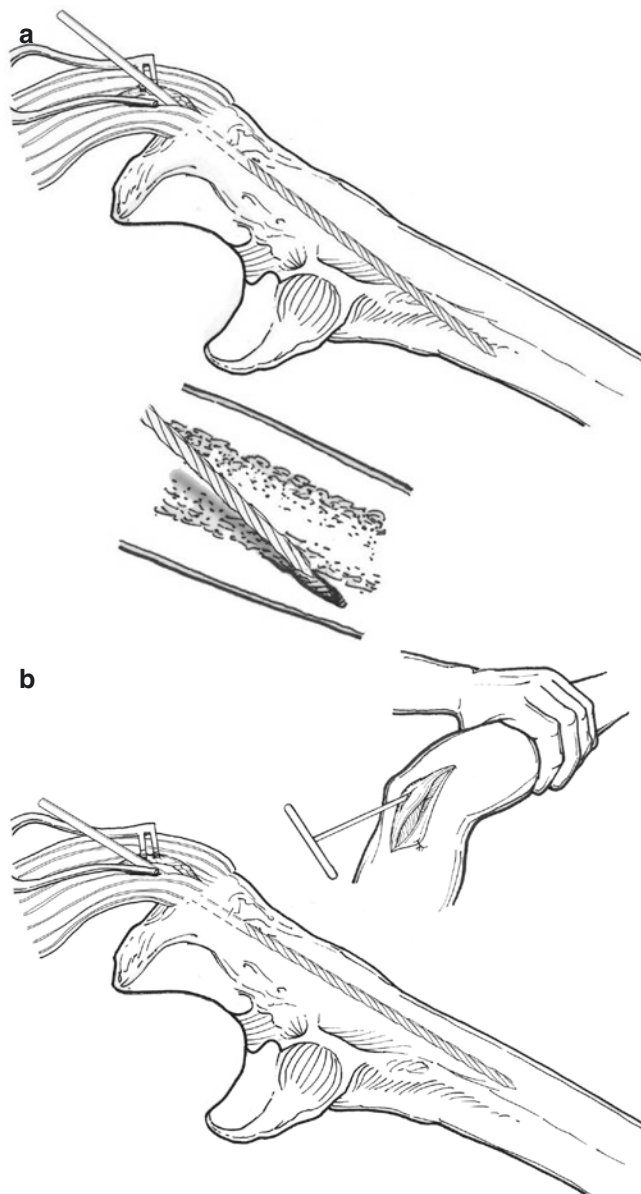




**Fig. 14.24** (a, b) Split performed on triceps

After drilling with the 3.2-mm drill bit, over-drilling with a 4.5-mm drill bit is carried out down to the coronoid, followed by tapping with a 6.5-mm tap. It is critical to tap until

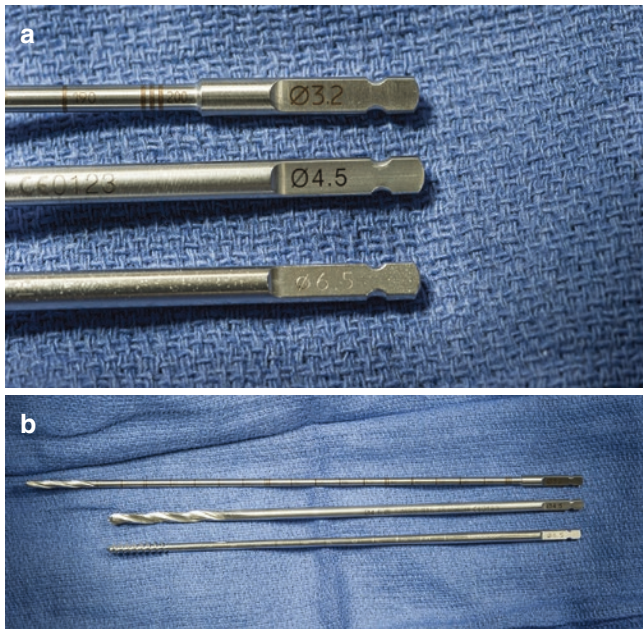
The drill bit is seated at the center of the olecranon in both projections and does not favor the radial side, as has been recommended, because of the curve of the ulna. The ability of the 6.5-mm solid screw to bend and follow the curve discounts any necessity for being off-center. The drill bit should not engage the endosteal surface, because this creates what is called a *shouldering effect* and could create a blind passage for subsequent steps (Fig. 14.25).



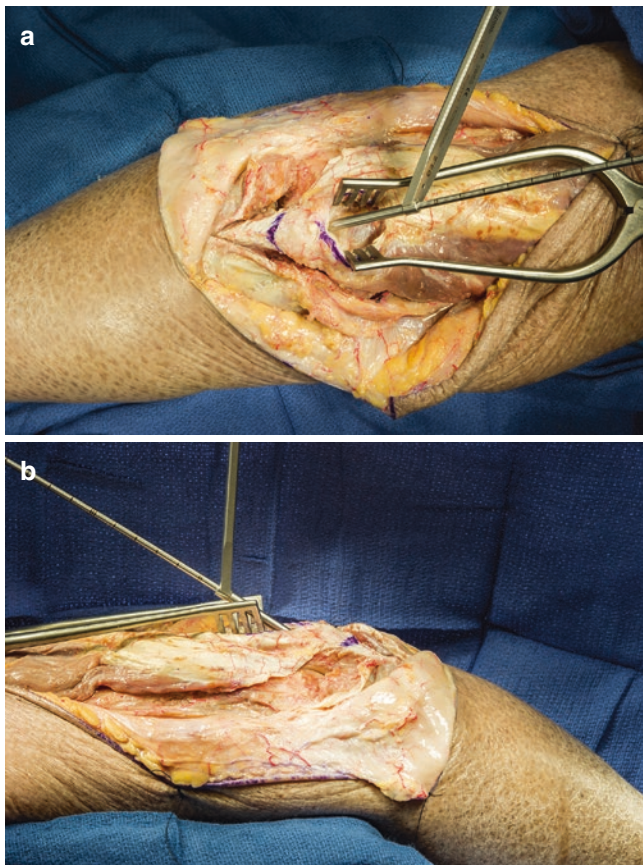
**Fig. 14.25** (a) Improper drilling engaging the endosteal surface, creating a shoulder and a potential blind path. (b) Proper drill orientation and hand position for tapping to resist forearm torque

a very good purchase is attained (Figs. 14.26, 14.27, 14.28, 14.29, 14.30, and 14.31).

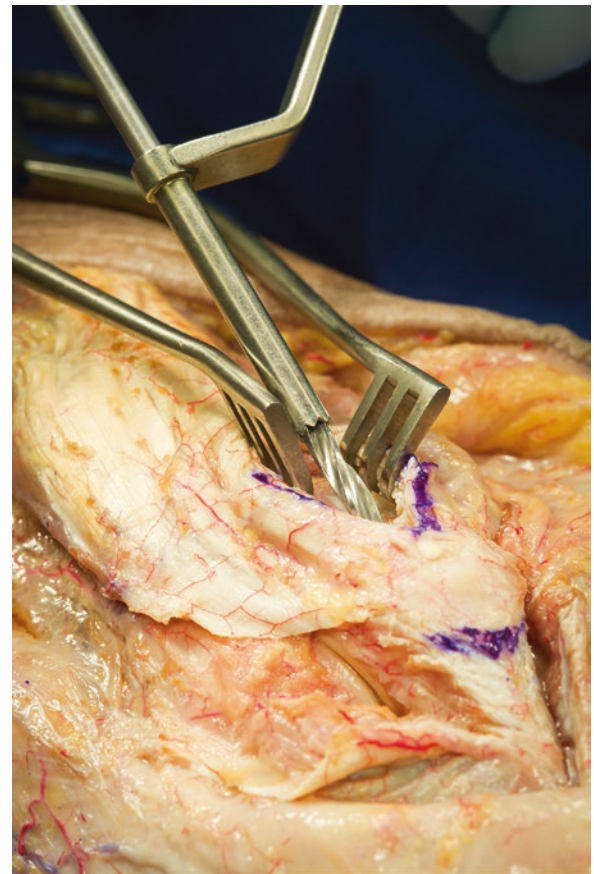




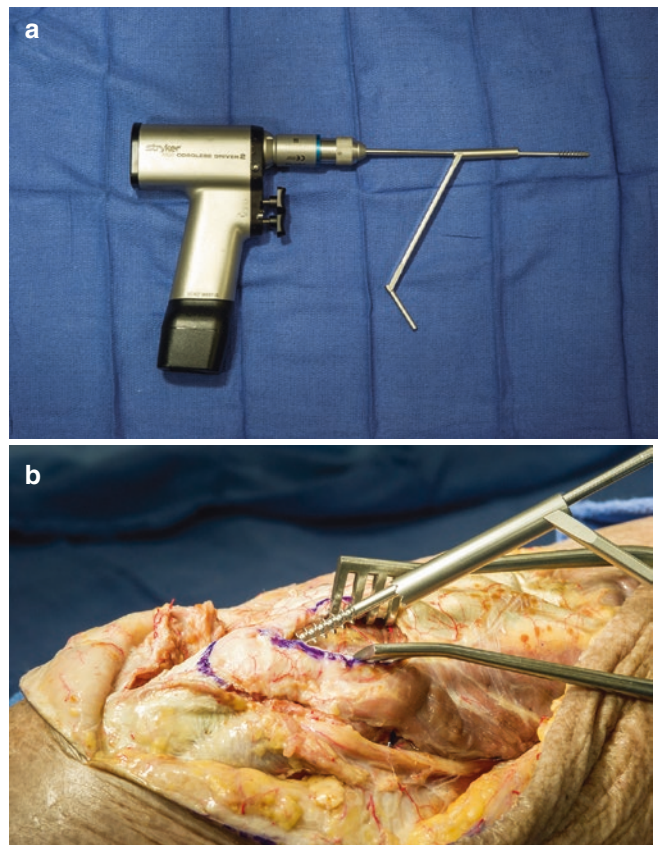
**Fig. 14.26** (a) Drills to be used in predrilling of olecranon osteotomy. (Predrill first; do not osteotomize first.) (b) 3.2-mm followed by 4.5-mm followed by 6.5-mm tap



**Fig. 14.27** (a) Begin with 3.2-mm drill bit in center of olecranon in both projections. Do not favor radially, but be in the center of olecranon; the 6.5-mm screw will bend and follow the contour of the ulna. (b) Do not force the drill bit; engaging the endosteal surface can develop a shoulder or false passage

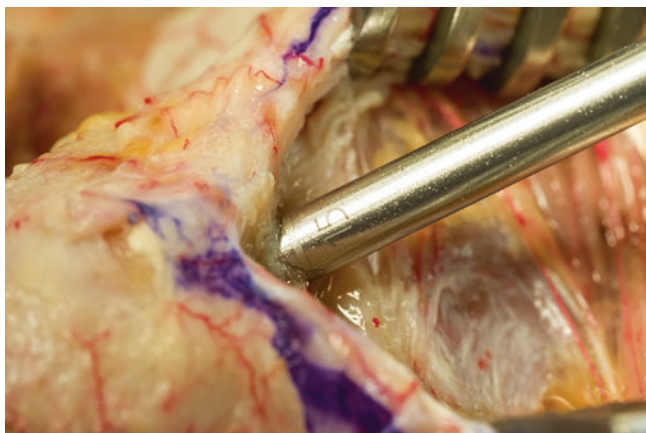


**Fig. 14.28** Over-drill to the level of the coronoid with the 4.5-mm drill bit



**Fig. 14.29** (a, b) Tap with 6.5-mm tap, beginning with power





**Fig. 14.30** Measuring using the tap, not the depth gauge

To allow compression, the selected screw should be 5 mm shorter than the tap length (Fig. 14.32).



**Fig. 14.32** Magnified view of ulna following tapping on 6.5-mm screw insertion, demonstrating tapping past screw length



**Fig. 14.33** Clinical example of osteotomy site outlined



**Fig. 14.31** Tap past screw length selected for a few turns to allow compression to account for saw kerf (bone removed with saw). The final turns of the tap must be very firm, associated with a few disconcerting “creaks.” Hold the forearm to resist torquing

If you can, tap to 150 mm, then go in a little further to use a 150-mm screw. A short screw is not indicated because it then acts as a big K-wire. The technique is an endosteal purchase fixation endeavor. The screw length is usually 140–150 mm. Occasionally, a 4.5-mm screw needs to be used in a smaller patient, and stepping up to a 7.3-mm screw occasionally may be required in an older patient with a bigger canal. Once the length is established, it is marked on the back table for the fixation at the end of the operation.

A chevron osteotomy is now outlined, with the apex of the chevron at the distal end of the bare area between the coronoid and the olecranon process (Figs. 14.33 and 14.34).



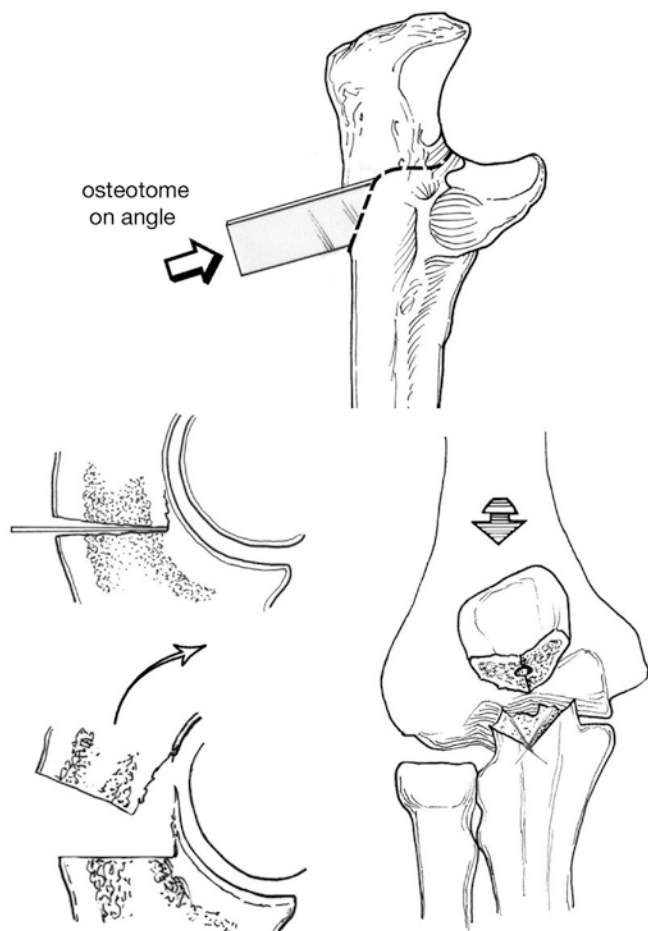
**Fig. 14.34** Osteotomy with cut apexing at bare area and angle of cut 60° on each limb. Use a thin blade



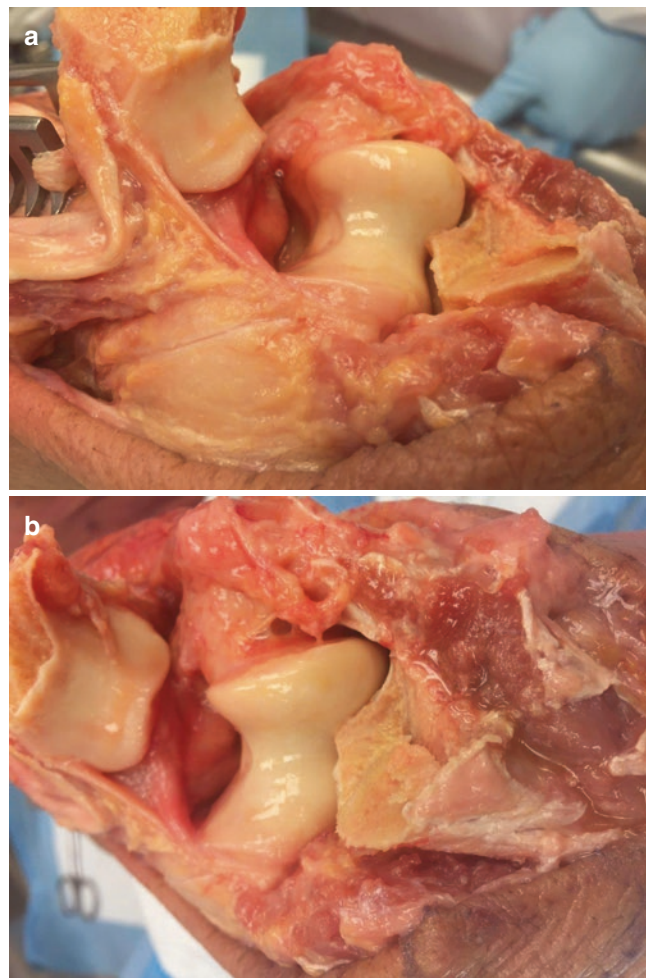
The chevron is about  $120^\circ$ . Care must be taken not to point the apex proximally, because when the screw goes in with an apex proximal orientation, the olecranon tends to split. In fact, it will split.

I use a sagittal saw. It is very important to ensure that the saw is perpendicular in all planes, because the tendency to drop your hand proximally can create an oblique cut that,

when reduced, will allow shearing as well as crisscrossing at the osteotomy. The result is an increased the amount of bone loss because of the saw kerfs. I also put a Freer elevator in the joint and lift to saw through, as completion with an osteotomy will frequently leave a ledge still attached to the bare area of the coronoid and block visualization (Figs. 14.35, 14.36, and 14.37).

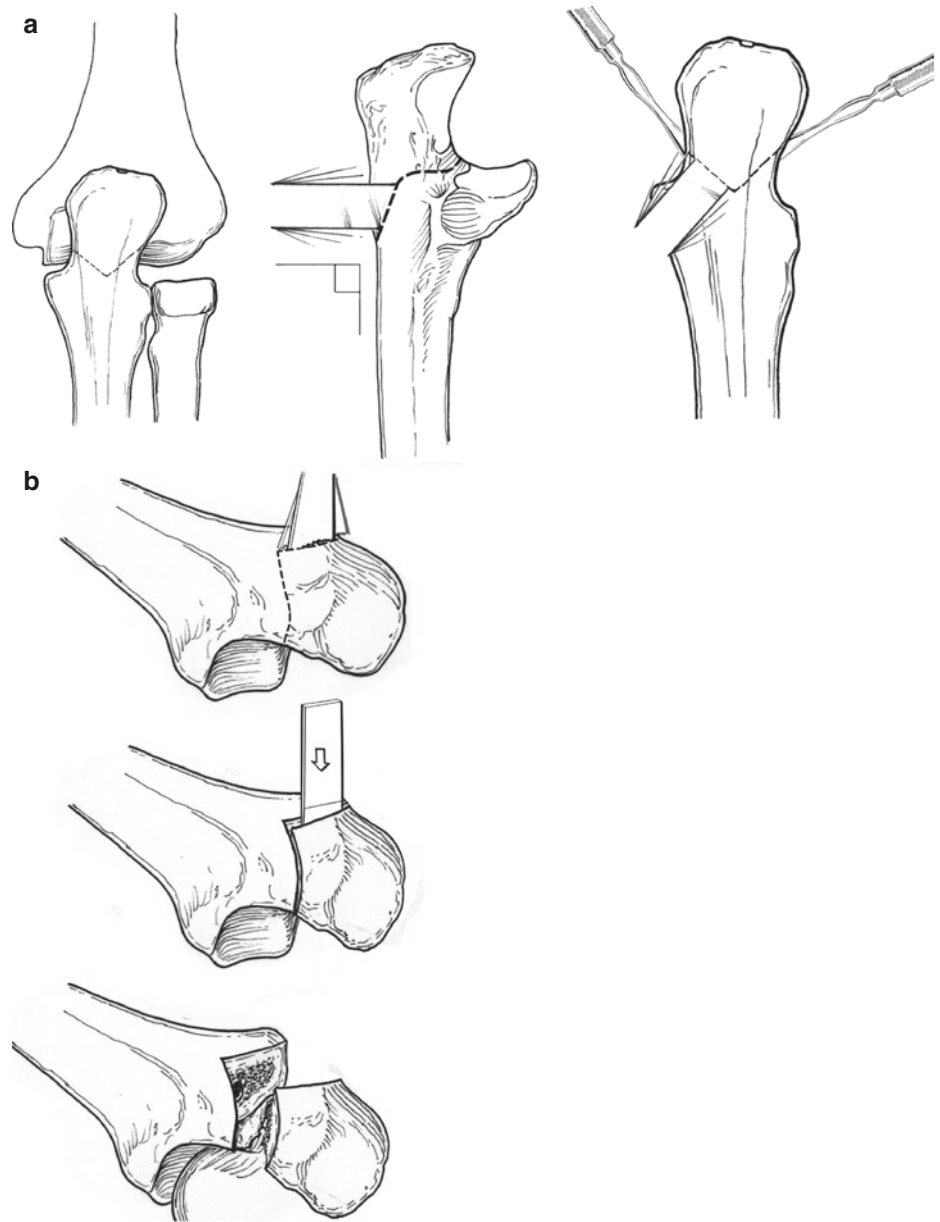


**Fig. 14.35** Diagram of oblique, shearing osteotomy, plus completing osteotomy with an osteotome and resultant ledge creation



**Fig. 14.36** (a, b) Cadaver demonstration of osteotomy completed with an osteotome and ledge creation

**Fig. 14.37** (a) Saw orientation with Freer elevator in the joint to protect the trochlea while sawing for the olecranon osteotomy. (b) Correct sagittal saw orientation



Once the osteotomy is completed, the triceps is retracted proximally and held to the drapes with a towel clip and hemostats (Fig. 14.38).



**Fig. 14.38** Osteotomized olecranon turned proximally out of field to left

The fracture is now prepared, including the debridement of open fractures. A substantial number of patients will have open fractures: 25, 41, and 42% in three papers [10, 12, 17]. At Shock Trauma, the average is close to 70% [18]. The fracture pattern is normally a transverse tension medially and comminution posterolaterally.

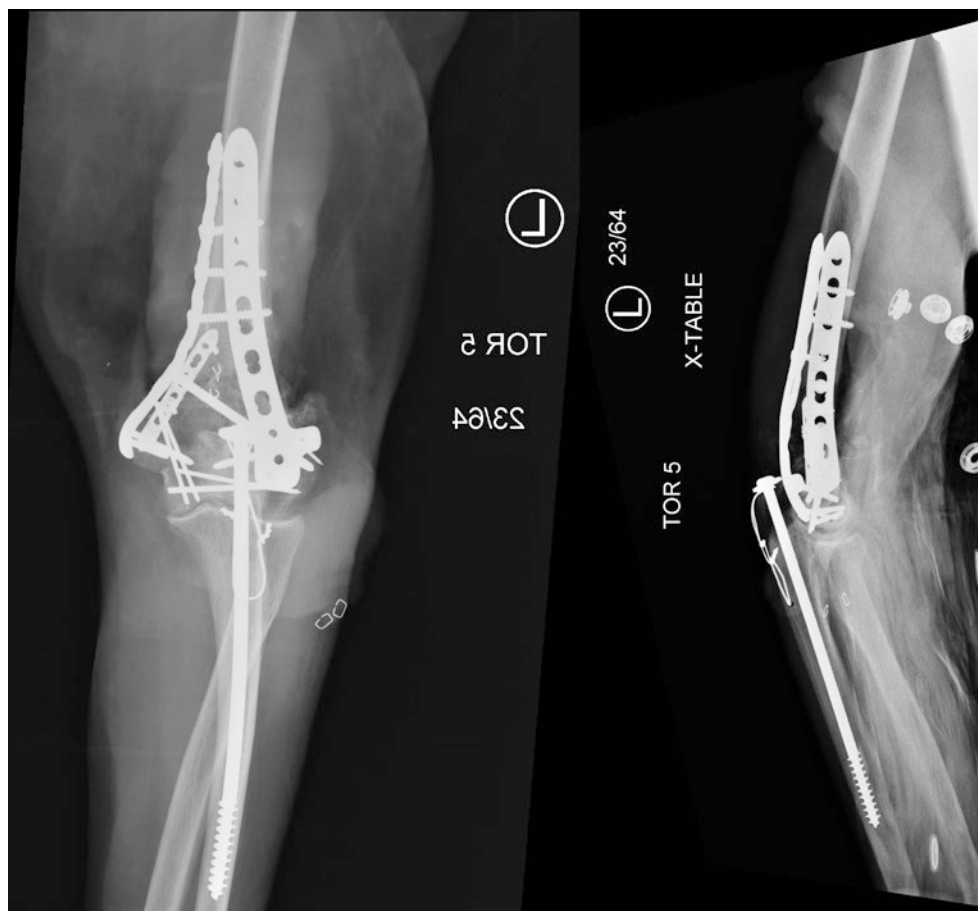
### 14.2.6 Fixation

The resident's next questions are along the lines of "What do you do first? Do you fix the joint, the columns—Exactly how do you go about it?" Believe it or not, I do not have a firm position of "how I always do it." Instead, I look at the comminution, I look at the keys, and I make a plan from there. If

I find a very comminuted intra-articular fracture, I secure the columns first, so that I do not block anterior access to the anterior joint comminution. That is very important. Therefore, I frequently rotate the major fragments to allow a sequential building of the articular components.

One needs to be sure that the medial trochlear ridge is not detached from the epicondyle, as this increases the complexity of subsequent fixation. If this situation does occur, I frequently use threaded Steinmann pins through the joint, exiting along the supracondylar ridge medially, with the threaded wires continued and to be backed out in a retrograde fashion, such that the threads are just beneath the subchondral bone. For this particular scenario, 2.4-mm or 3.0-mm headless screws are advantageous (Figs. 14.39, 14.40, 14.41, 14.42, 14.43, 14.44, and 14.45).

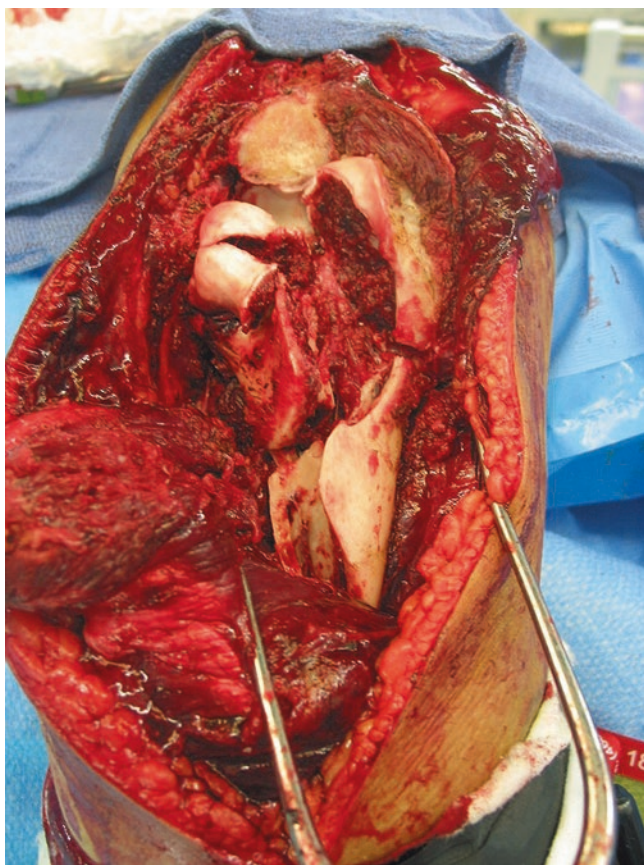
**Fig. 14.39** Intraoperative radiographs demonstrating threaded Kirschner wires (K-wires) securing the trochlea to the medial column (same case as in Fig. 14.1)



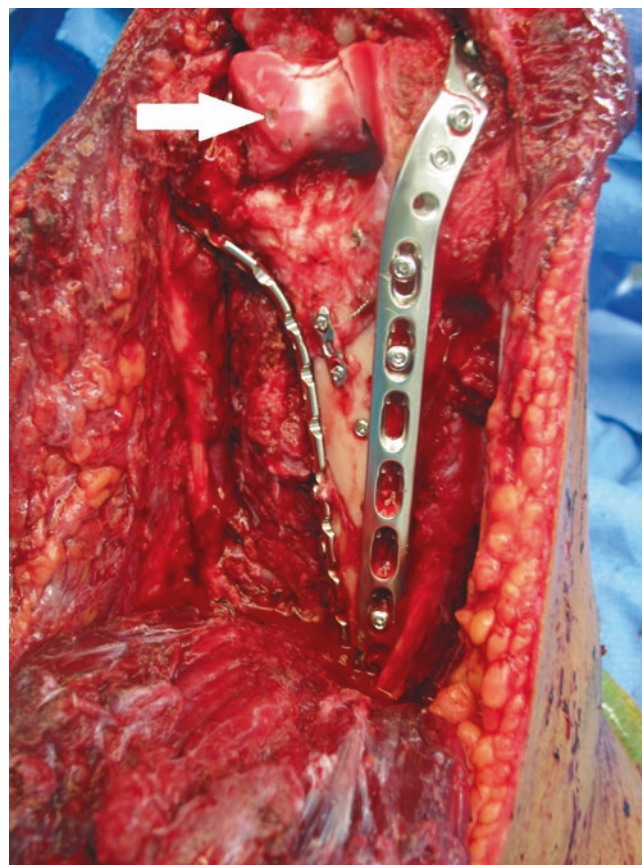




**Fig. 14.40** Injury radiographs

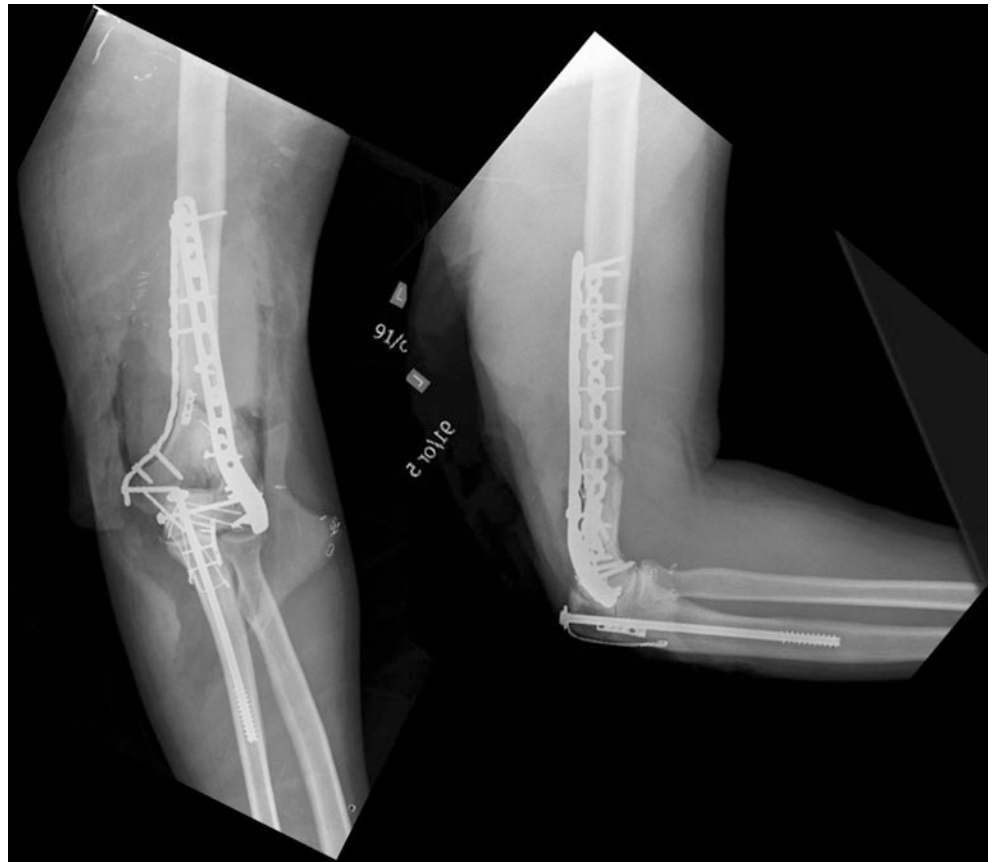


**Fig. 14.41** Intraoperative image with ORIF performed with arm across chest on Mayo

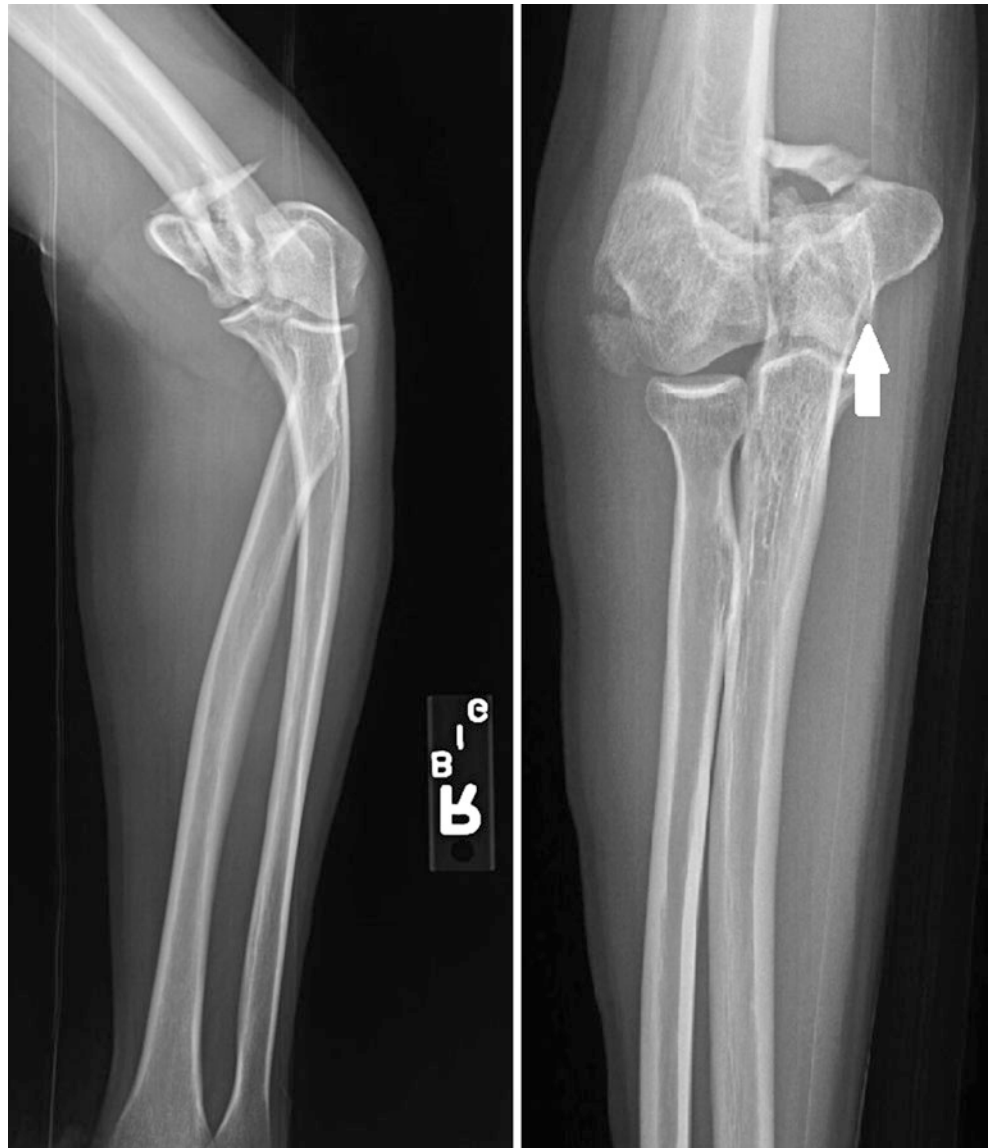


**Fig. 14.42** Fixation revealing buried treated K-wires burred to recess (arrow)

**Fig. 14.43** Radiographs following fixator



**Fig. 14.44** Injury radiographs of distal humerus fracture and medial trochlea fracture (*arrow*)

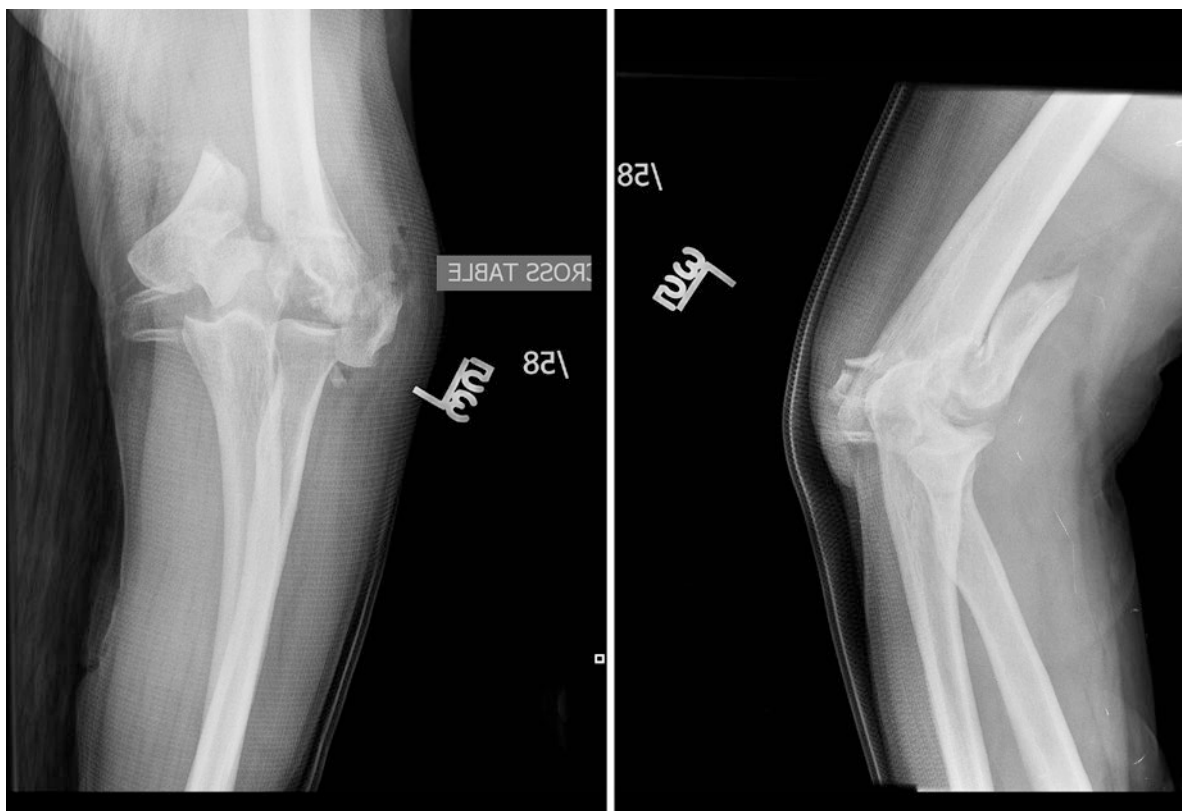




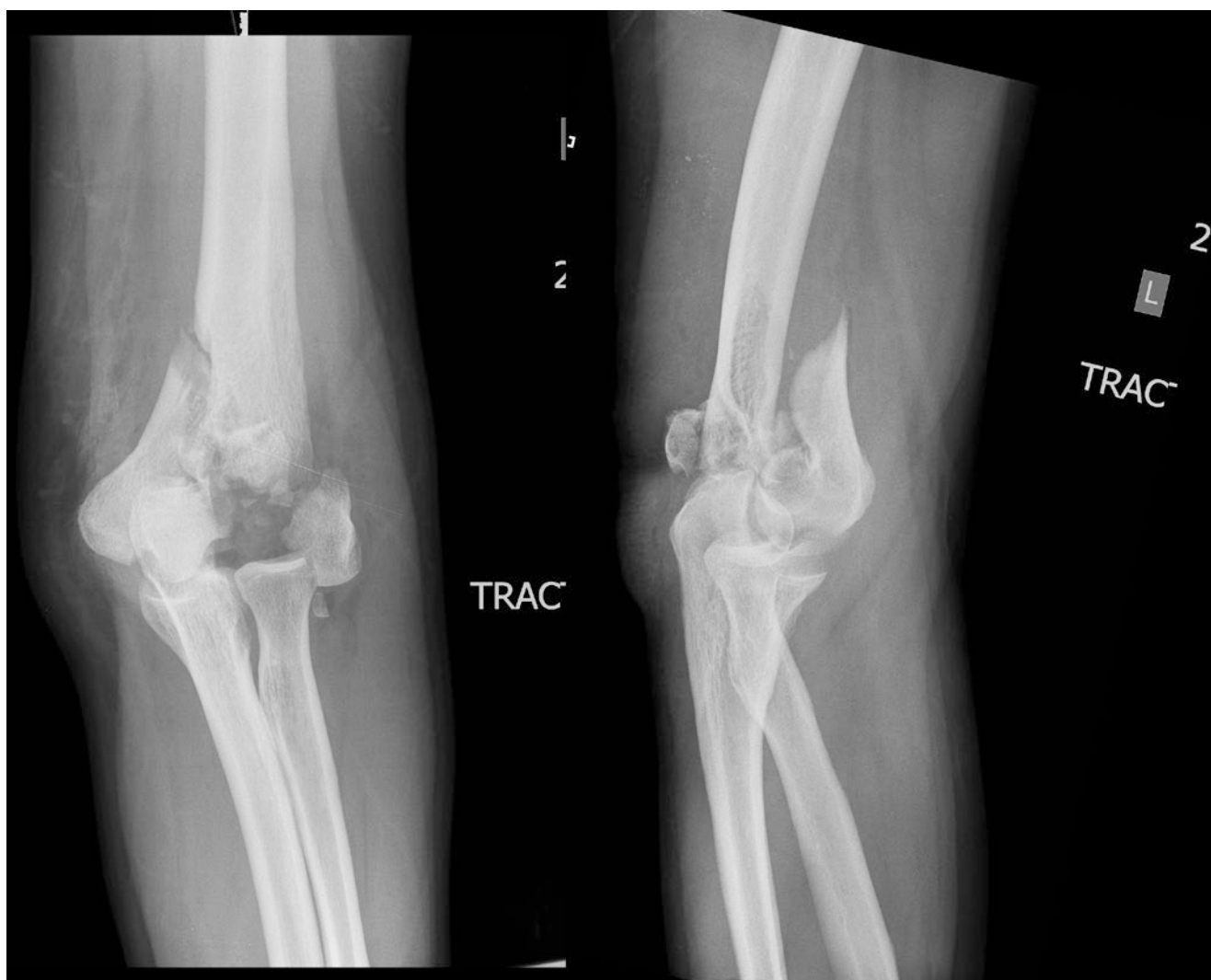
**Fig. 14.45** Intraoperative radiograph demonstrating medial trochlea fracture with headless screw



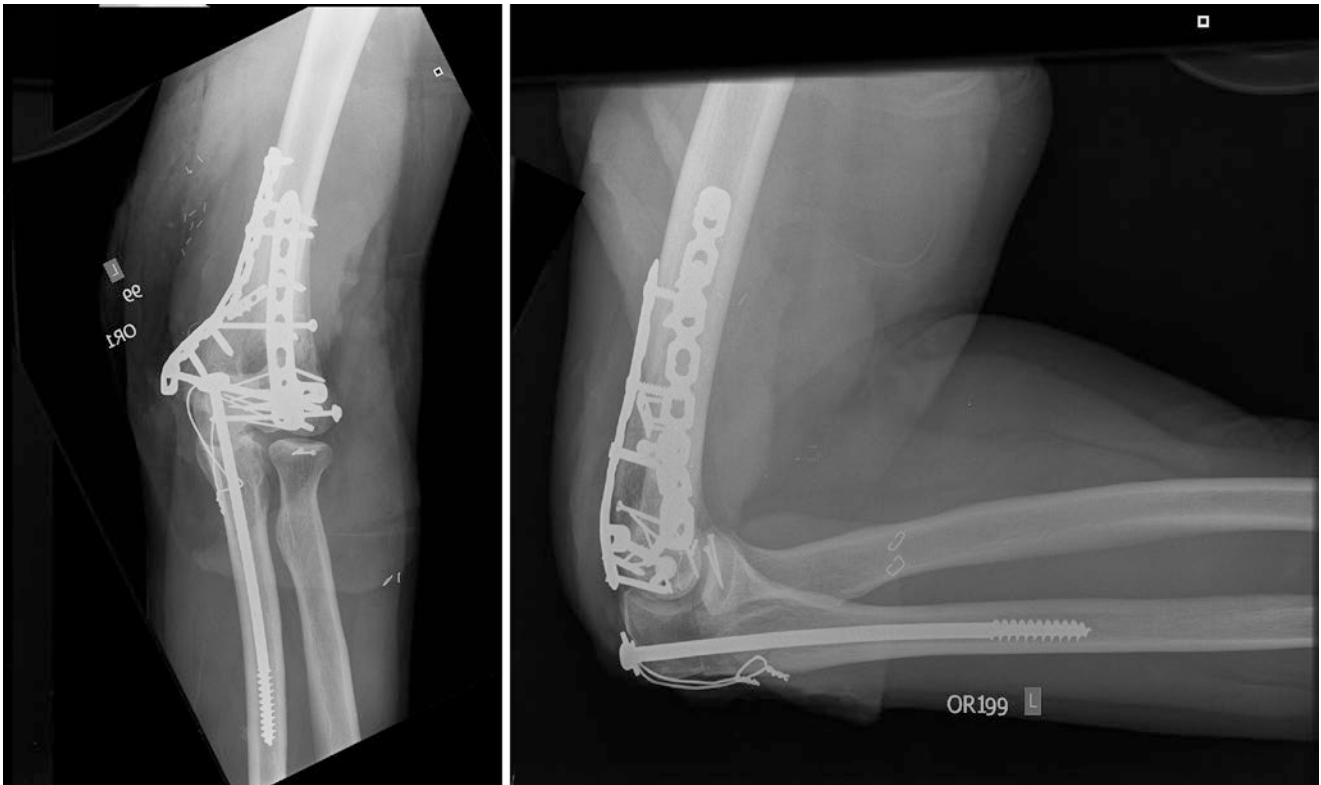
If I am stacking on articular fragments, I frequently use smooth K-wires, as these become incarcerated in the bone and have less tendency to migrate (Figs. 14.46, 14.47, and 14.48).



**Fig. 14.46** Presentation injury radiographs of open left distal humerus fracture



**Fig. 14.47** Traction radiographs of left distal humerus

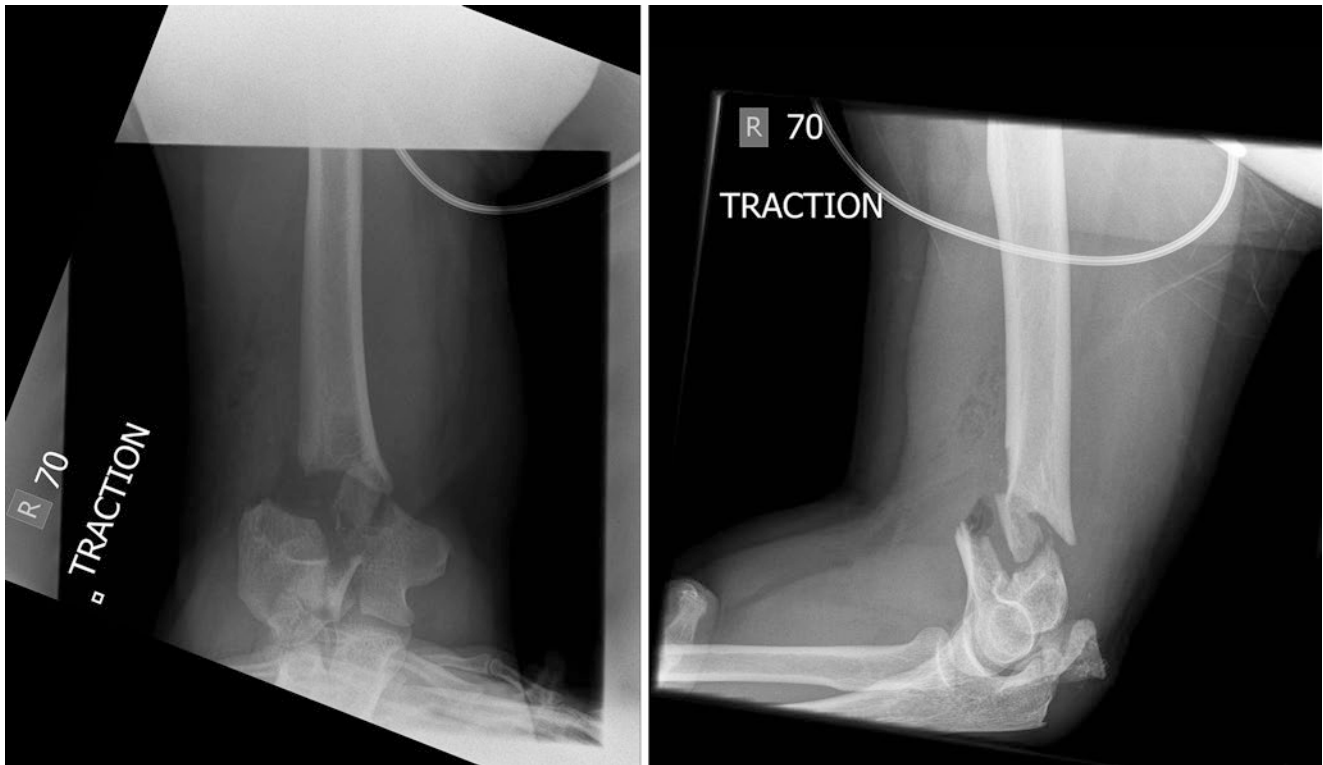


**Fig. 14.48** Intraoperative radiographs demonstrating numerous K-wires utilized in stacking fashion for multiple fragments, with K-wires incarcerated in bone

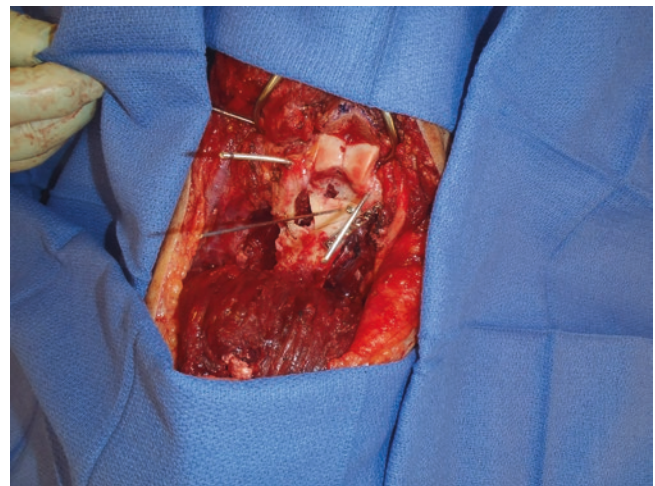


Occasionally, I predrill, using a 1.1-mm drill bit for insertion of wires, if I am having difficulty with the fragments, and then I insert the K-wires. Once the joint has been reconstructed, I hope that the reconstruction will result in two

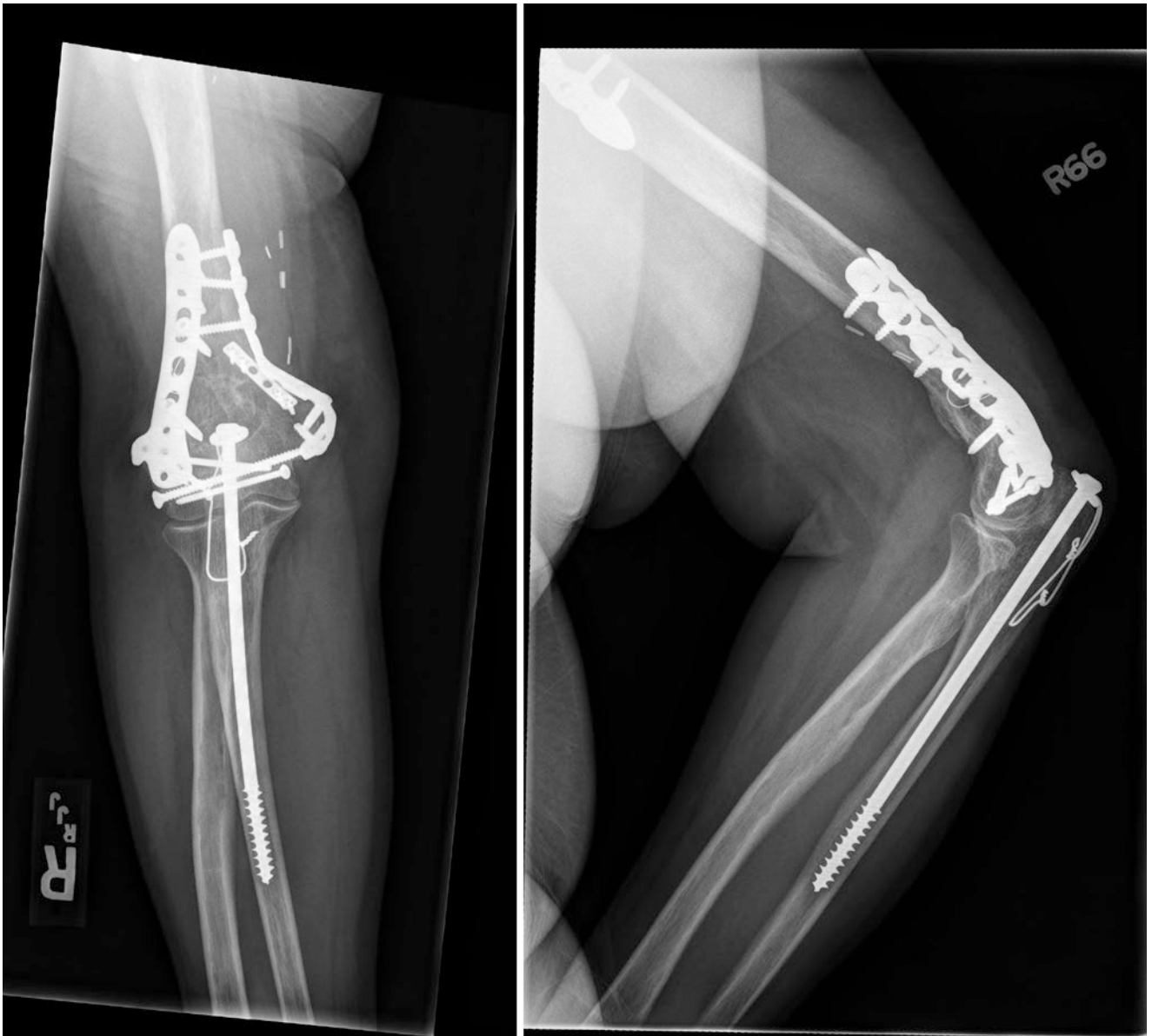
main fragments; then a large tenaculum can be used to secure the joint reduction. This is followed by provisional 0.0625 K-wires. Threaded Steinmann pins are useful as joysticks (Figs. 14.49, 14.50, and 14.51).



**Fig. 14.49** Traction radiographs of right distal humerus fracture



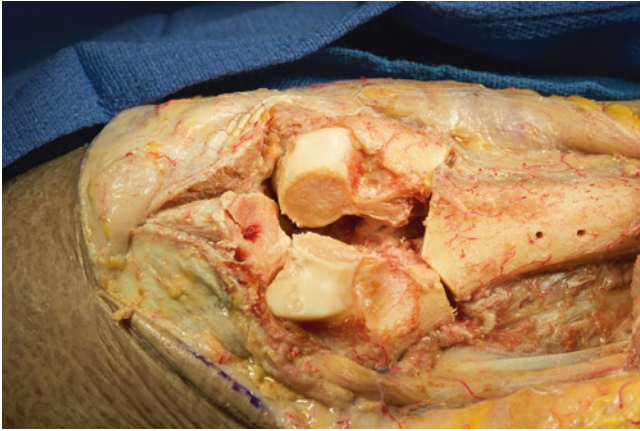
**Fig. 14.50** Intraoperative demonstration of threaded Steinmann pins used as joysticks, plus mini-fragment plate, screws, and interosseous wires for provisional fixation



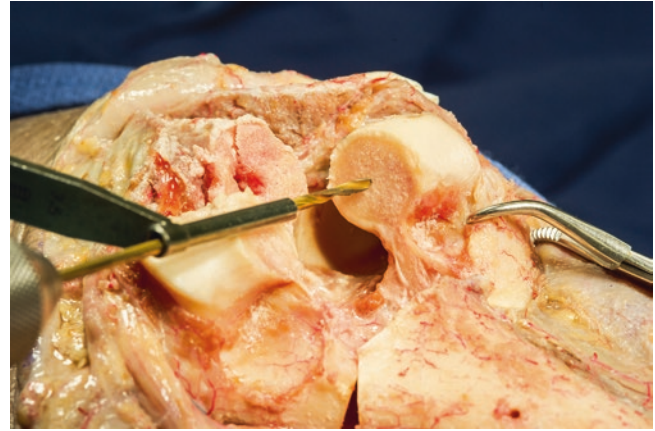
**Fig. 14.51** Radiographs of healed distal humerus at time of discharge

Usually some form of transcondylar screw is used: either a 2.7-mm screw from medial to lateral just distal to the medial epicondyle, or lateral to the medial with either a

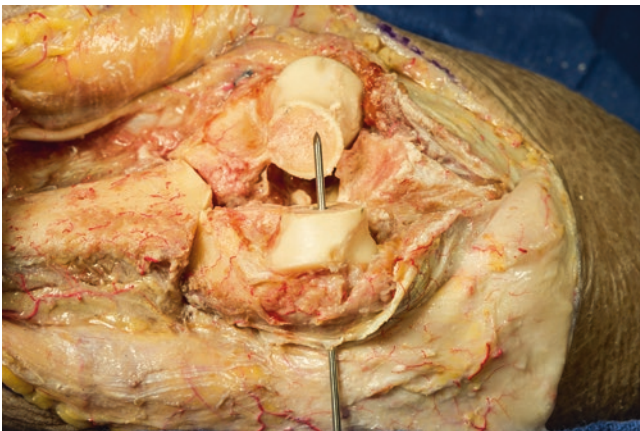
2.7-mm or 3.5-mm screw (Figs. 14.52, 14.53, 14.54, 14.55, 14.56, and 14.57).



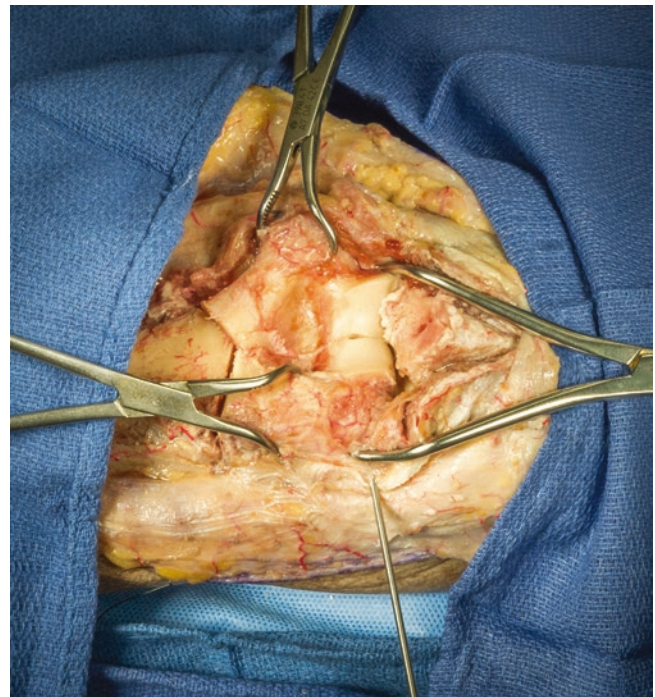
**Fig. 14.52** Simulated T intercondylar fracture



**Fig. 14.53** Performing inside-out predrilling with bicondylar fixation; predrill with a 2.5-mm drill bit through the lateral fragment



**Fig. 14.54** 2.0-mm K-wire placed through drill hole in lateral condyle

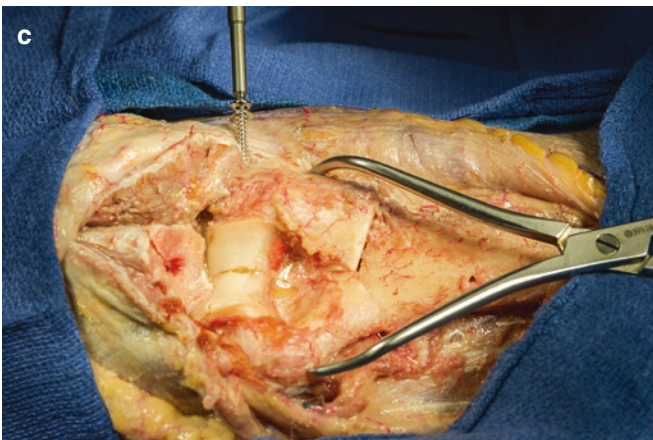
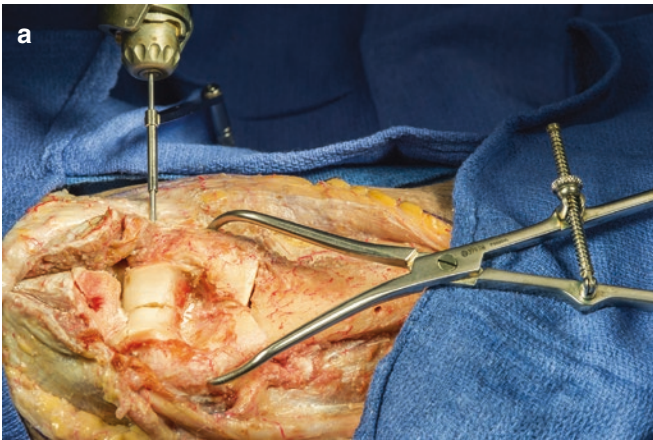


**Fig. 14.55** Reduction performed with a small tenaculum, then held with a large tenaculum on K-wire advanced across to medial condyle





**Fig. 14.56** Medial-to-lateral 2.7-mm lag screw without over-drilling or countersinking; the bone will usually “self” countersink

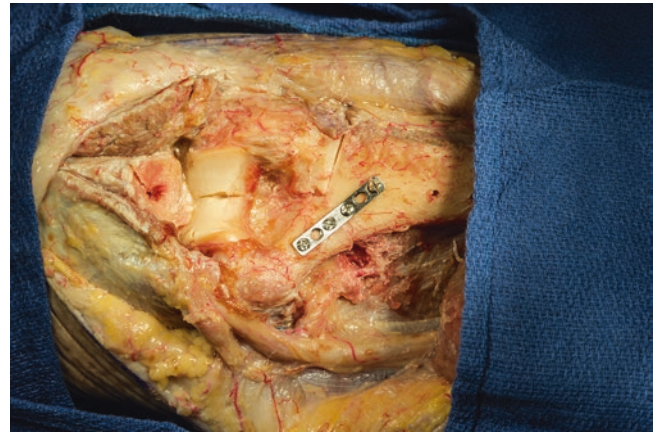


**Fig. 14.57** (a) Lateral-to-medial screw with 3.5-mm cortical. (b) K wire removed, drilling with 2.5 mm drill bit. (c) 3.5 mm cortical screw with washer insertion

Once the major articular fragments are together, fixation of the joint complex usually begins with a mini-plate along the posterior aspect of the medial supracondylar region, as

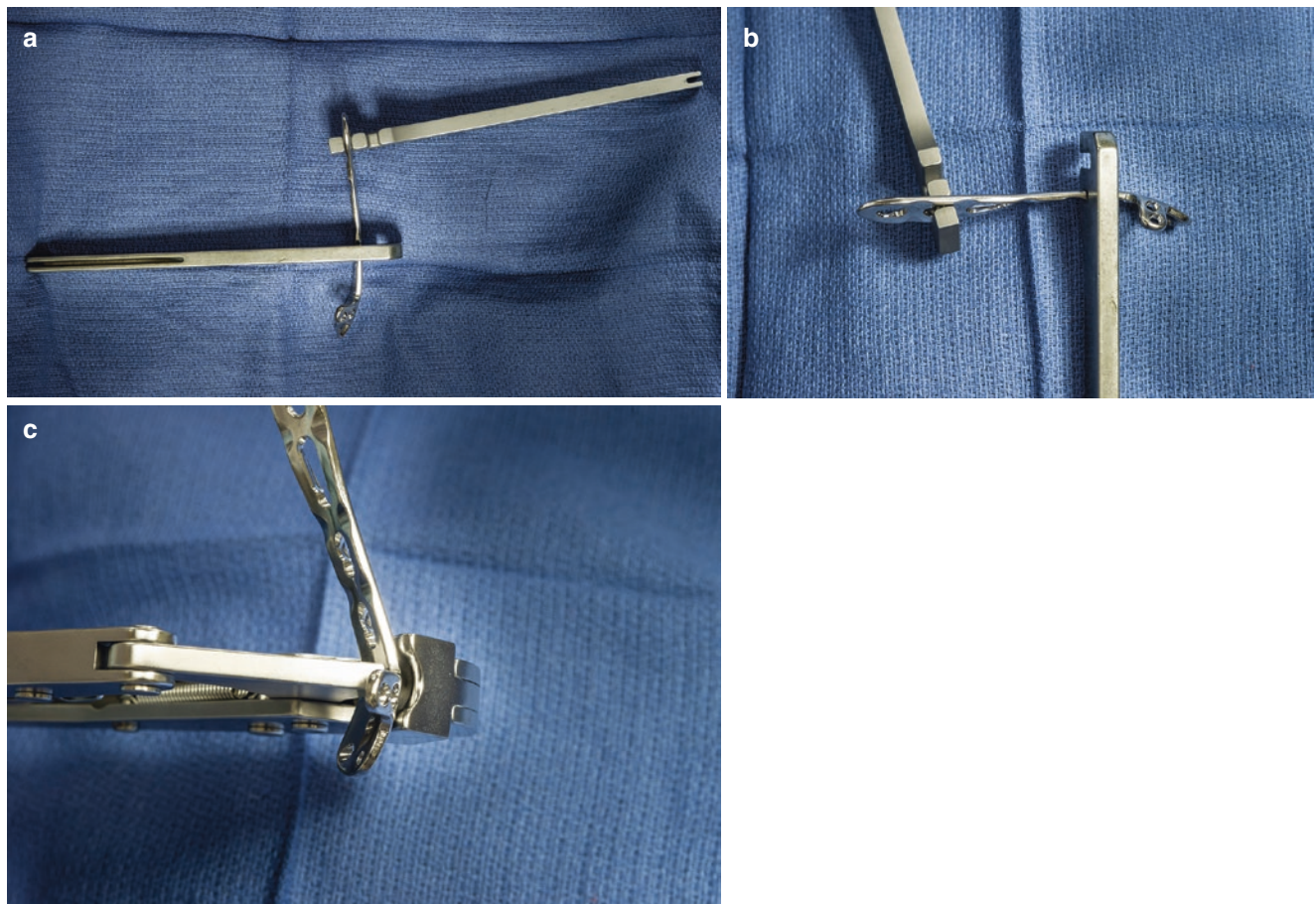
this tends to be more of a transverse tension fracture and will allow a mini-plate to be placed without blocking your medial sagittal plate (Fig. 14.58).

**Fig. 14.58** Provisional posteromedial fixation with a 2.0-mm dynamic compression plate (DCP)



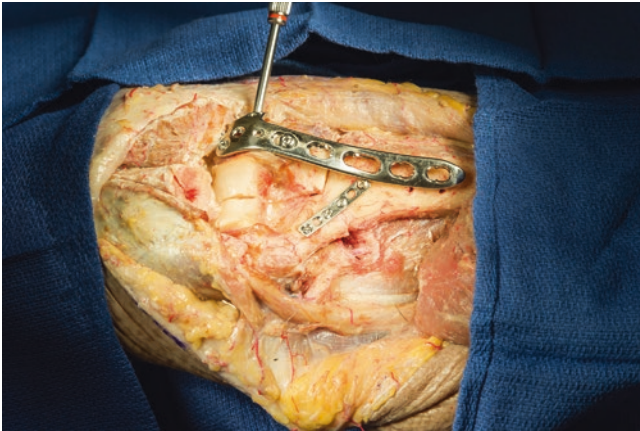
The mini-plate is followed by a lateral plate positioned posteriorly with a construct that has a flange for a transverse screw,

depending on the degree of articular comminution and the need for further transcondylar screws (Figs. 14.59 and 14.60).



**Fig. 14.59** Bending posterolateral definitive plate. (a, b) The Synthes supracondylar plate needs to be bent with more curve anteriorly, then twisted to wrap the flange around more anteriorly. (c) Cupping of distal end of plate to better contour to the lateral condyle posteriorly





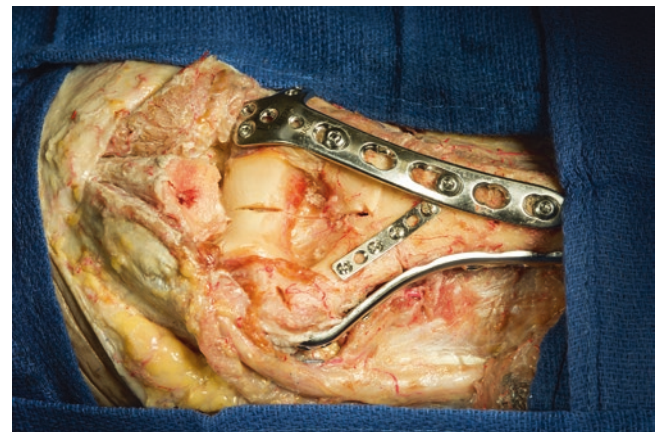
**Fig. 14.60** Definitive plate fixation laterally with a cortical screw followed by a locking screw

Allow me a digression: You may wonder where the idea comes from to use mini-fragment plates, lag screws, and interosseous wire as reduction devices for provisional fixation. Many years ago, I was fortunate to have the opportunity to observe Dr. Paul Manson (one of the founders of craniofacial trauma surgery) perform what seemed like an endless number of bicoronal flaps for facial trauma. Way back then, cars had lap belts but no shoulder harnesses, so when sudden deceleration occurred, the face would smack into the steering wheel. As I watched Dr. Manson put a myriad of facial fractures together, I thought I could use

some of his techniques to help hold bone fragments together while definitive fixation is applied, thus decreasing surgery time and preserving soft tissue by limiting reduction clamp use. We also didn't have a throng of people to help out with trauma cases. Thus the mini-plate and wire application was born.

Definitive medial plate fixation can use a predesigned medial plate; instead, I like to use a 3.5-mm reconstruction plate ("recon plate") contoured to allow a locking screw to go across both condyles and effectively become a fixed-angle device (Fig. 14.61).

**Fig. 14.61** Compression screws placed proximally laterally followed by the definitive medial sagittal plate, again generally with distal screws first, followed by compression screws proximally





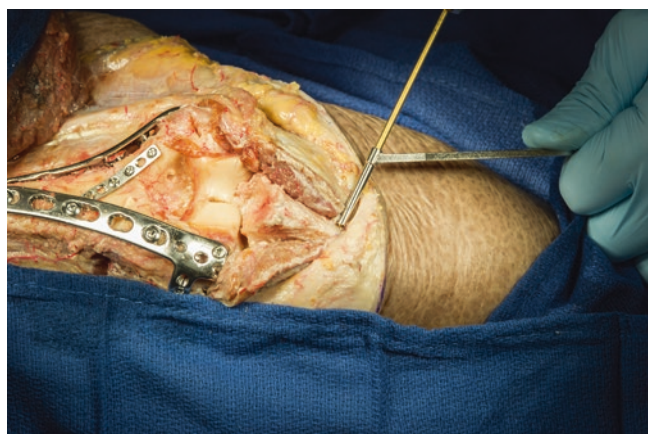
Regarding open fractures and intra-articular fragments, the detached articular fragments in an open fracture can be reused, depending on their degree of contamination or the degree to which they are open. I debride and irrigate the fragments, and frequently soak them in diluted Betadine before their reuse. Occasionally, I will use periarticular fragments, if they are critical from a reduction or stabilization standpoint, but these are commonly removed once the overall construct is in place.

Also, in either an open or closed fracture, I may use allograft cancellous bone mixed with antibiotic powder (usually vancomycin), particularly in older patients, once the trochlea is reconstructed. There frequently is a cancellous defect, as if the trochlea is a canoe; in this case, I pack the bone graft from proximal to distal in the reconstructed articular components.

The next point of controversy concerns the orientation of plates. I favor medial sagittal and posterior lateral plating. Effectively, every potential plate orientation scenario has

been discussed. Henley *et al.* [17] cited Mehne and Matta [19] in describing plate location in four different positions. Both posterior plates and bilateral sagittal plates have been espoused [20, 21]. However, a medial plate posterior has potential for impingement from the olecranon process on the medial plate. Numerous studies look at the virtues of plate orientation. With the present plate design and metallurgy, I believe it is difficult to be dogmatic as to the exact plate orientation, though I would suggest that there is risk of failure and nonunion if using third tubular plates or the weaker plates, particularly in the supracondylar region. Also, not all screws need to engage the plate, given that the transcondylar screws frequently are outside the plate fixation. Once the articular reconstruction and fixation is completed, the wound undergoes about 3 L of jet lavage. The closure is performed with new gloves and a new down sheet or towel.

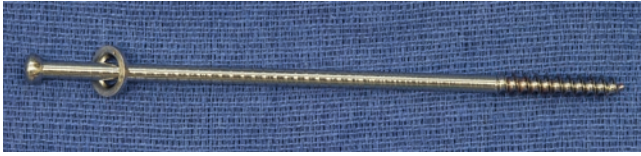
The olecranon osteotomy will now be secured. A 2.0-mm or 2.5-mm drill hole is made approximately 2.5 cm distal to the apex of the olecranon osteotomy (Fig. 14.62).



**Fig. 14.62** Drilling medial to lateral 2.5 cm distal to the osteotomy with a 2.5-mm drill bit, bicortical but not far enough in the canal to block the 6.5-mm screw. Place 18-gauge wire through the hole prior to screwing

The hole is drilled in a fashion that will not interfere with subsequent screw insertion. An 18-gauge wire is inserted, but not pulled all the way through the hole, as there is a tendency for screw threads to notch the wire, causing a potential point of weakness. To resist torquing

and osteotomy displacement, two reduction clamps are used to hold the shaft as well as the olecranon osteotomy. A 6.5-mm screw, with 32-mm thread over a washer, is inserted in the previously made split in the triceps (Figs. 14.63 and 14.64).



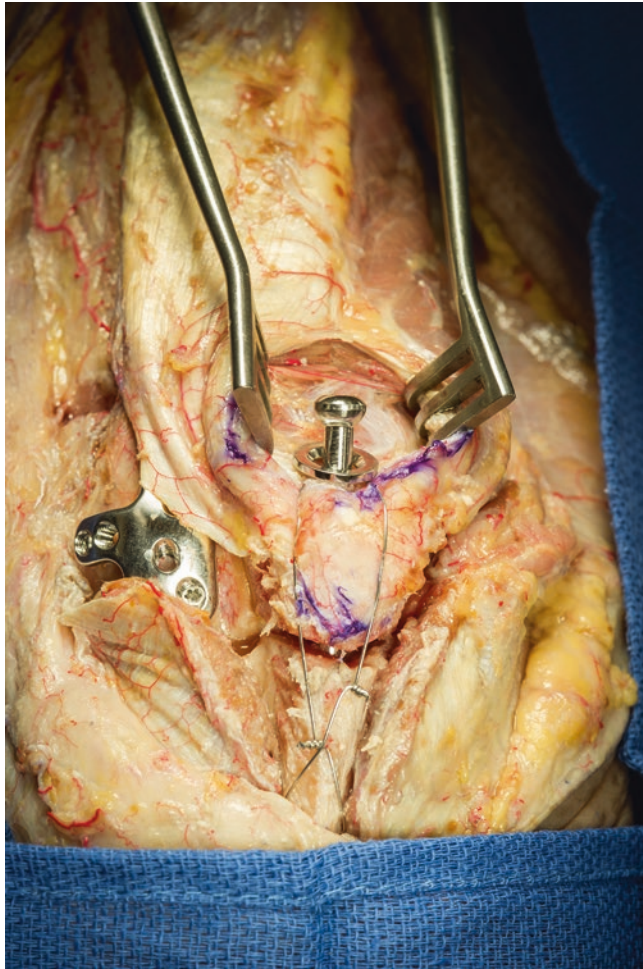
**Fig. 14.63** 6.5-mm screw (not cannulated), with washer



**Fig. 14.64** 6.5-mm screw insertion

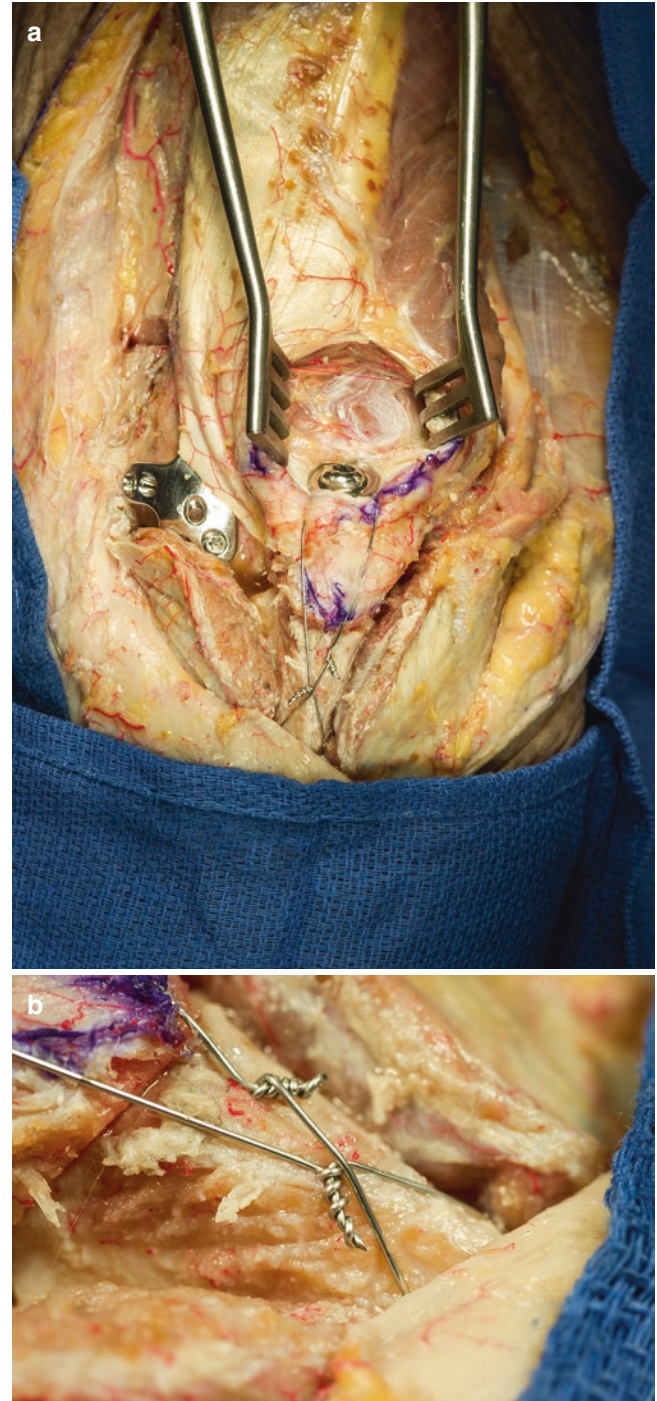


The screw is advanced while the reduction is held, making sure to place the 18-gauge wire deep to the washer prior to provisional seating. Once the provisional seating has been undertaken, the double-twist tension band wire is undertaken, but not taken to full tensioning (Fig. 14.65).



**Fig. 14.65** 6.5-mm screw partially inserted; wire is placed around the screw and partially tightened with two twists in figure-eight fashion

Final screw tightening is performed, followed by tensioning of the wires by twisting and turning the wires down at the same time (Fig. 14.66).



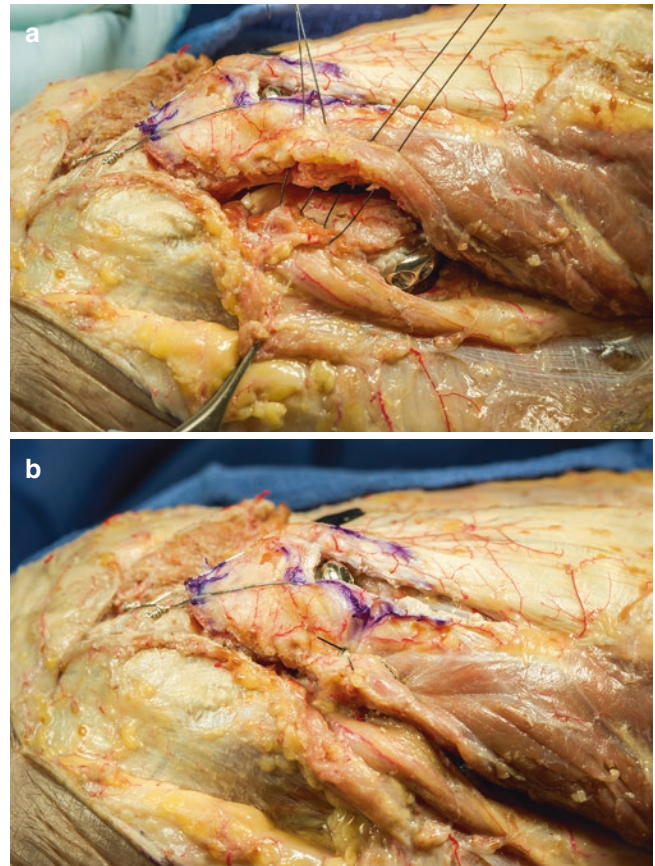
**Fig. 14.66** (a, b) Finish seating the 6.5-mm screw; then do final tension band wire twisting and turning. (Note: The wire shown is not 18-gauge. Smaller wire was used because of availability)



The screw is the main source of the compression. If the wire breaks, the screw can be backed out and a new wire inserted. Radiographs should be obtained at this time. I frequently obtain radiographs prior to reduction of the olecranon osteotomy.

The ulnar nerve is repositioned in the cubital tunnel, and I use two 4-0 Vicryl® sutures in a horizontal fashion, with both of sutures being placed prior to tying. The nerve is now brought back into the tunnel, held with the Vicryl® sutures (Fig. 14.67).

**Fig. 14.67** (a, b) Two horizontal sutures are placed in the soft tissue, periosteum beneath the ulnar nerve, not over it. Both sutures are placed prior to tying

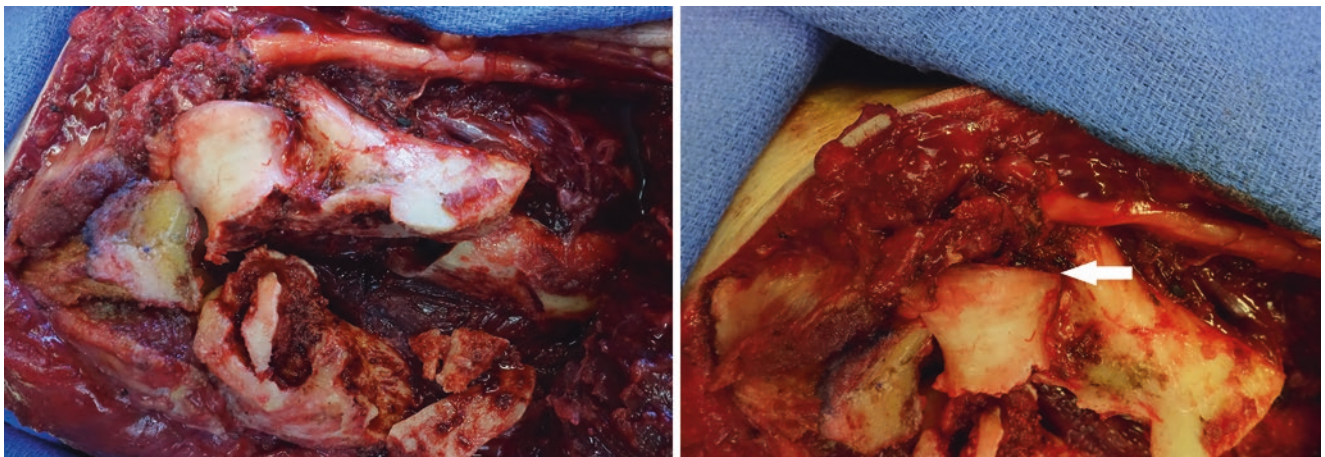


The skin approximation further supports the nerve in the cubital tunnel, as medial dissection has not been performed on the nerve. The fascial approximation distally is performed with buried 2.0 PDS to the level of the epicondyle laterally. I do not do any further deep closure. A medium HemoVac™ drain is placed laterally, exiting proximally. Skin closure is

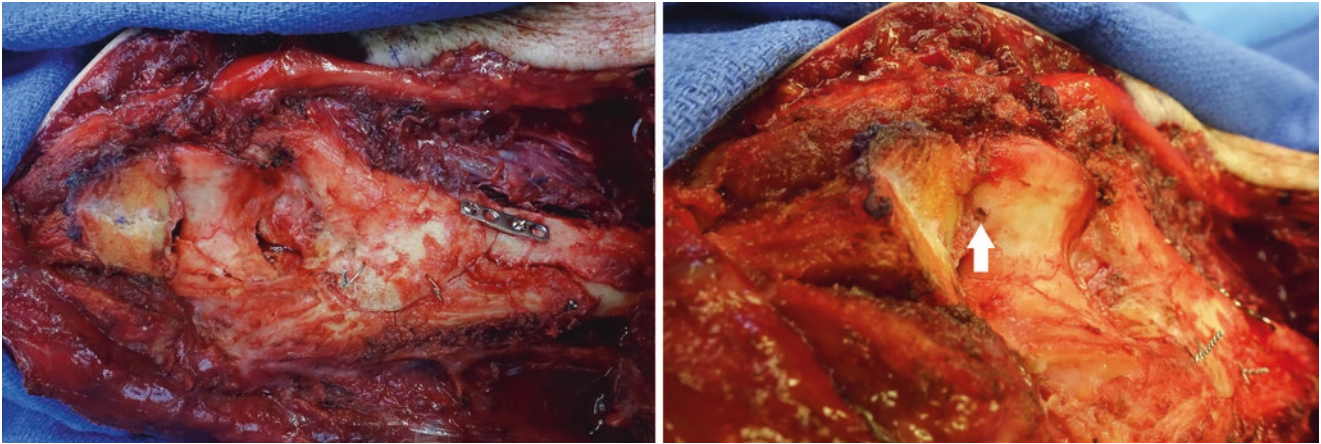
with 2-0 Vicryl®, 4-0 Vicryl®, and 3-0 Prolene®. The arm is placed in a long arm posterior splint with the elbow at 30°–45° to relax the tension on the skin and on the osteotomy; preventing the elbow from starting in a flexed position also helps to avoid subsequent flexion contracture (Figs. 14.68, 14.69, 14.70, 14.71, and 14.72).



**Fig. 14.68** Injury and traction radiographs of right distal humerus fracture. Note trochlea medial epicondyle fracture (*arrow*)

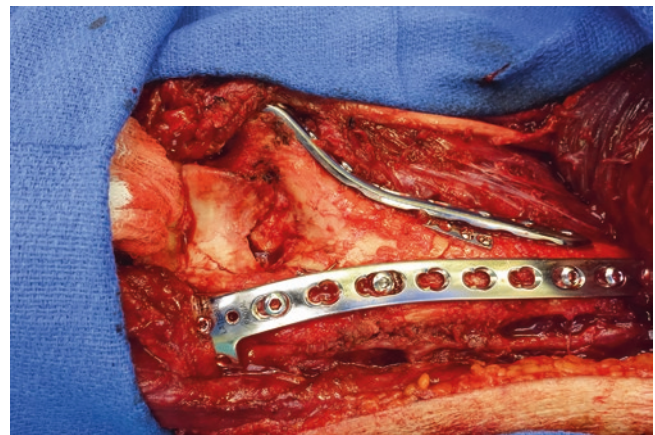


**Fig. 14.69** Intraoperative demonstration of trochlea medial column fracture (*arrow*)



**Fig. 14.70** Provisional fixation with view of headless screw buried in trochlea (*arrow*)

**Fig. 14.71** Final definitive fixation







**Fig. 14.72** Postoperative radiographs of headless screw (*arrow*)

### 14.2.7 Patient Rehabilitation and Counseling

Patient range of motion (active and active assist) is started 1 or 2 days postoperatively, with no weight-bearing or strengthening. If a splint was used, it generally is discarded 4–6 weeks after surgery. Dynamic splinting, if required, can be instituted at 6 weeks; strengthening is begun at 8 weeks and weight-bearing at 3 months. Patients are counseled that their arm will never function 100% normally, but it should function well. Frequently, a patient will ask, “If I’m not going to be normal, what is normal?” You likely try to refrain from verbalizing your first thoughts in order to advise the patient that they should compare the range of motion of their injured elbow with that of their other elbow. The normal range of motion, approximately 140°–145°, can vary predicated upon body habitus.

When asked what is the normal “functional range of motion,” residents are obligated to recite the 130°/30° flexion/extension established by Morrey *et al.* and 50/50 pronation/supination. A subsequent project by Vasen *et al.* [23] looked at functional range of motion and found the range to be 120°/75°, with an arc of 45°. When a more recent paper reviewed the range of motion, it set the functional range of motion in flexion and extension at 149°/27°, probably because of today’s necessity to use the cell phone [24]. Pick your paper.

What are the published outcomes of T-intercondylar distal humeral fractures? When results were reviewed in a number of papers, the good to excellent range-of-motion arc or flexion and extension was found to be 100°–110° (Table 14.1). Open fractures were found to have worse functional outcomes than closed fractures [29, 30].

**Table 14.1** Results of open reduction and internal fixation

Study	Year	Patients (n)	Range of motion: Arc F/E
Holdsworth and Mossad [25]	1990	57	115°
McKee <i>et al.</i> [26]	2000	25	108°
Gupta and Khanchandani [13]	2002	55	130°
Doornberg <i>et al.</i> [14]	2007	30	106°
Ek <i>et al.</i> [27]	2008	7	90°
Greiner <i>et al.</i> [28]	2008	12	103°
Erpelding <i>et al.</i> [21]	2012	37	126°

F/E flexion/extension

Nonoperative treatment is seldom considered. However, a 1971 article by Brown and Morgan [31] reviewed ten patients with intercondylar T-shaped fractures of the humerus, including five open fractures. The patients were placed in slings for a few days. Active range of motion began at 6 weeks. Union was noted in all patients, with a resultant flexion/extension arc of 98° (range, 70°–130°); the average range of motion was 130/30°, and only one patient required a change of occupation [31]. In a study comparing outcomes in 21 patients, Ryu *et al.* [32] reported good outcomes in approximately 70% of patients who were surgically treated but only 27% of those treated nonsurgically.

Patients need to be counseled on the potential for capsulectomies, particularly with multiple traumatic injuries and open fractures, which we know tend to have poorer results. Capsulectomies are commonly requested by patients to improve flexion and extension. In a study by Cannada *et al.*, the flexion/extension range of motion improvement was approximately 18° [18]. A recent unpublished review on adolescents with T-intercondylar fractures at Shock Trauma revealed improvement of 19° following capsulectomy. Capsulectomies are not generally performed before 6 months from surgery, unless the patient has developed a dense contracture, limiting motion below a 20° arc. In this situation, a second capsulectomy may be required at some time because the contracture will tend to recur.

### 14.3 Total Elbow Arthroplasty, Hemiarthroplasty, ORIF

Finally, a comment on distal humeral fractures and total elbow arthroplasty (TEA). The optimal treatment of intercondylar T-fractures in the elderly is controversial. There are papers supporting ORIF or TEA, as well as comparison studies [33–35] (Tables 14.2 and 14.3).

**Table 14.2** Results of total elbow arthroplasty in the elderly

Study	Year	Patients (n)	Average age (years)	Range of motion: Arc F/E
Cobb and Morrey [36]	1997	20 (21 elbows)	72	105°
Gambirasio <i>et al.</i> [37]	2001	10	85	101°
Kaminen and Morrey [38]	2004	48 (49 elbows)	67	107°
Ali <i>et al.</i> [39]	2010	20	72	98°

F/E flexion/extension

**Table 14.3** Results of open reduction and internal fixation in the elderly

Study	Year	Patients (n)	Average age (years)	Range of motion: Arc F/E
Pereles <i>et al.</i> [40]	1997	18	71	112°
Huang <i>et al.</i> [41]	2005	19	72	111°
Srinivasan <i>et al.</i> [42]	2005	21	85	78°
Korner <i>et al.</i> [43]	2005	45	73	100°
Huang <i>et al.</i> [44]	2007	23	77	92°
Liu <i>et al.</i> [45]	2009	35	69	103°

F/E flexion/extension

Regardless of the technique, however, the rate of complications is high: 11–31% in ORIF and 11–35% in TEA. Studies that compare ORIF to TEA favor TEA. The complications—particularly if the joint implants require removal—are devastating, resulting in a flail arm if a resectional arthroplasty is

performed. I have performed only one primary TEA for a distal humeral fracture; this patient was a low-demand patient with rheumatoid arthritis. *Note:* I am a fan of hemiarthroplasty and was having encouraging clinical results until that option was curtailed (Figs. 14.73 and 14.74).



**Fig. 14.73** Injury radiographs of right distal humerus in 80-year-old patient





**Fig. 14.74** Radiographs following hemiarthroplasty

## 14.4 Fixation for Medial and Lateral Condyle Fractures

For the sake of complete discussion without adding another chapter, I will comment here about condyle fractures. I approach medial condyle fractures as if they were a T-intercondylar fracture: the patient is positioned laterally

and the fracture is approached using a medial paratricipital vantage (Fig. 14.70).

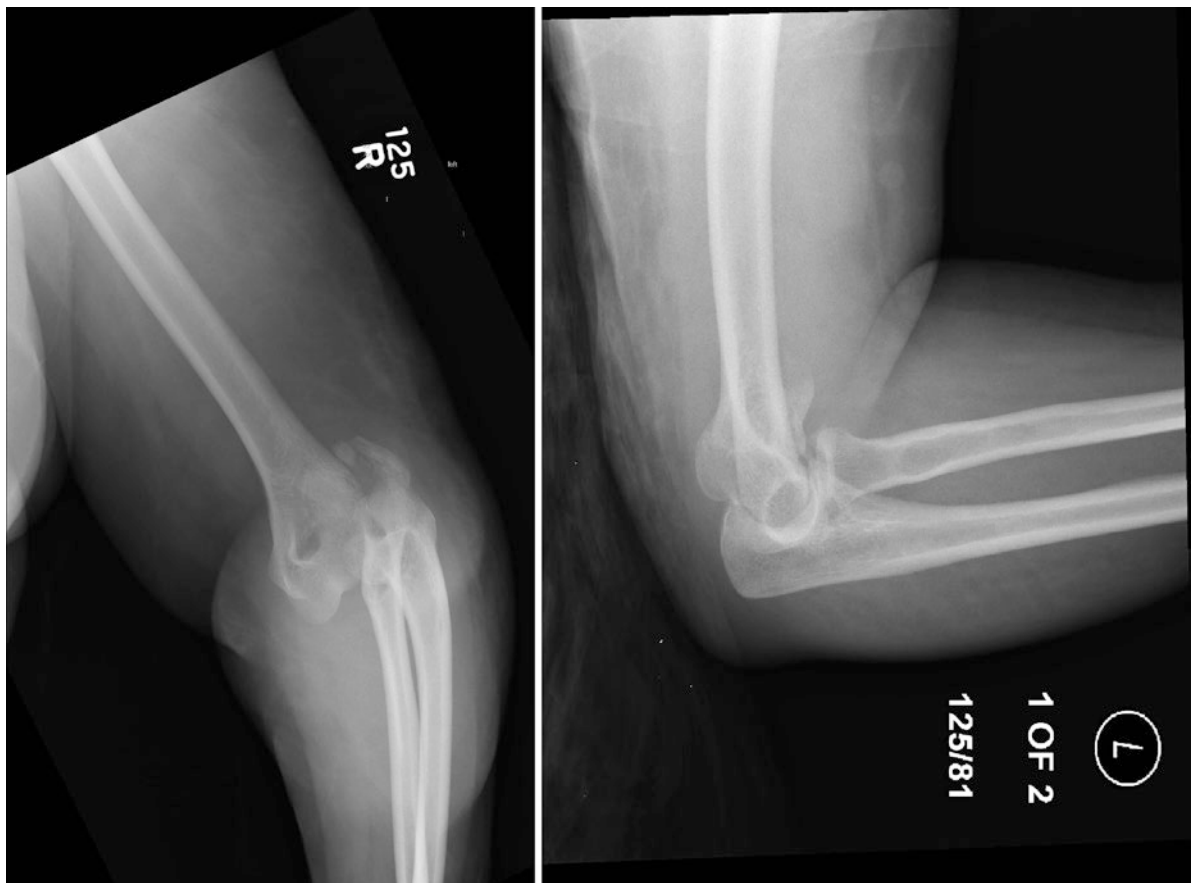
Lateral condyle fracture fixation usually is approached with the patient supine; a lateral incision is utilized. The fixation is commonly backed up with an external fixator (Figs. 14.75, 14.76, 14.77, 14.78, and 14.79).

**Fig. 14.75** Injury radiographs of right distal humerus medial condyle fracture





**Fig. 14.76** Final radiographs at time of discharge

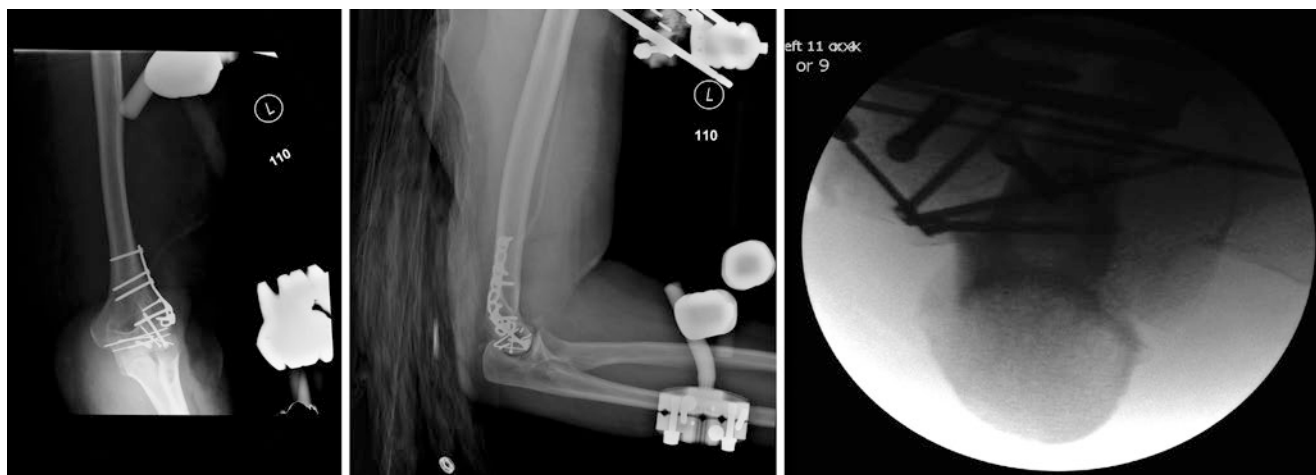


**Fig. 14.77** Injury radiographs of left distal humerus lateral condyle fracture





**Fig. 14.78** Traction radiographs



**Fig. 14.79** Intraoperative radiographs following ORIF and external fixation, including cubital tunnel view

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15.1 Issues Defining Anterior Shear Injuries and Treatment Approach

The use of CT scans probably has credence for the evaluation of anterior shear fractures of the distal humerus, unlike their overly zealous use in evaluating distal humerus T-intercondylar fractures, trans-olecranon fracture disloca-

tions, or “terrible triads.” The rarity of this injury has led to a series of reports with relatively small numbers of patients, which generally reflect good function and range of motion. Anterior shear fractures with posterior comminution or more complexity tend to fare slightly worse, but no negative impact on outcomes was reported when the injury was associated with radial head fractures (Table 15.1).

Table 15.1 Results of Anterior Shear Fractures of the Distal Humerus

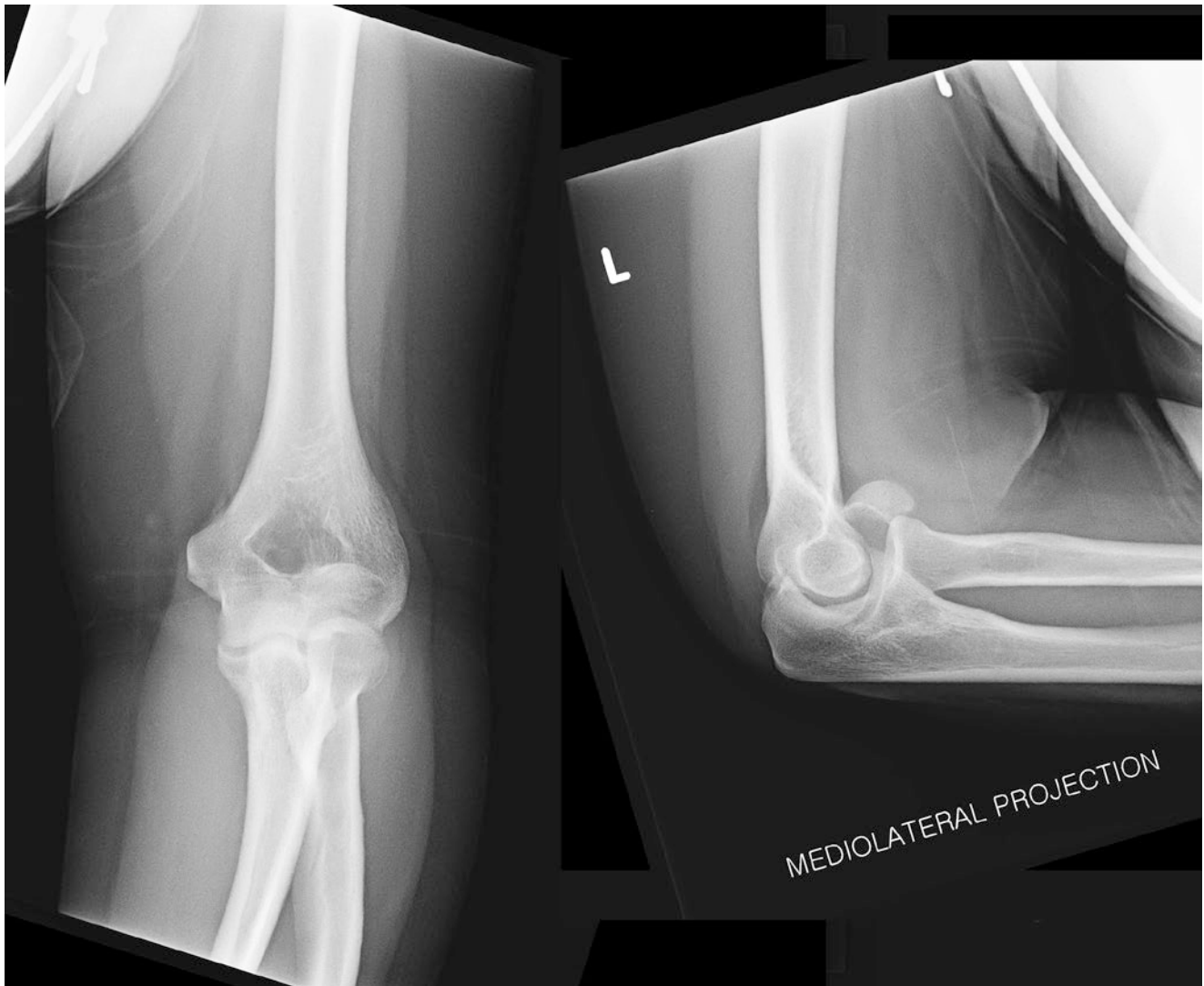
Study	Year	Patients, <i>n</i>	F/E, <i>degrees</i>	Arc
McKee <i>et al.</i> [1]	1996	6	141/15	–
Ring <i>et al.</i> [2]	2003	21	140/55	96°
Dubberley <i>et al.</i> [3]	2006	28	138/19	119°
Ruchelsman <i>et al.</i> [4]	2008	18	–	128°
Mighell <i>et al.</i> [5]	2010	18	–	128°

F/E flexion/extension

Three issues need to be addressed relative to the anterior shear injury. First, is the injury truly only anterior shear, and not extending posteriorly (thus masked as a T-intercondylar fracture)? Second, is the trochlea involved? I have rarely seen a pure capitellar fracture; a small portion of the trochlea is almost always involved. Third, what is the best approach to the fracture?

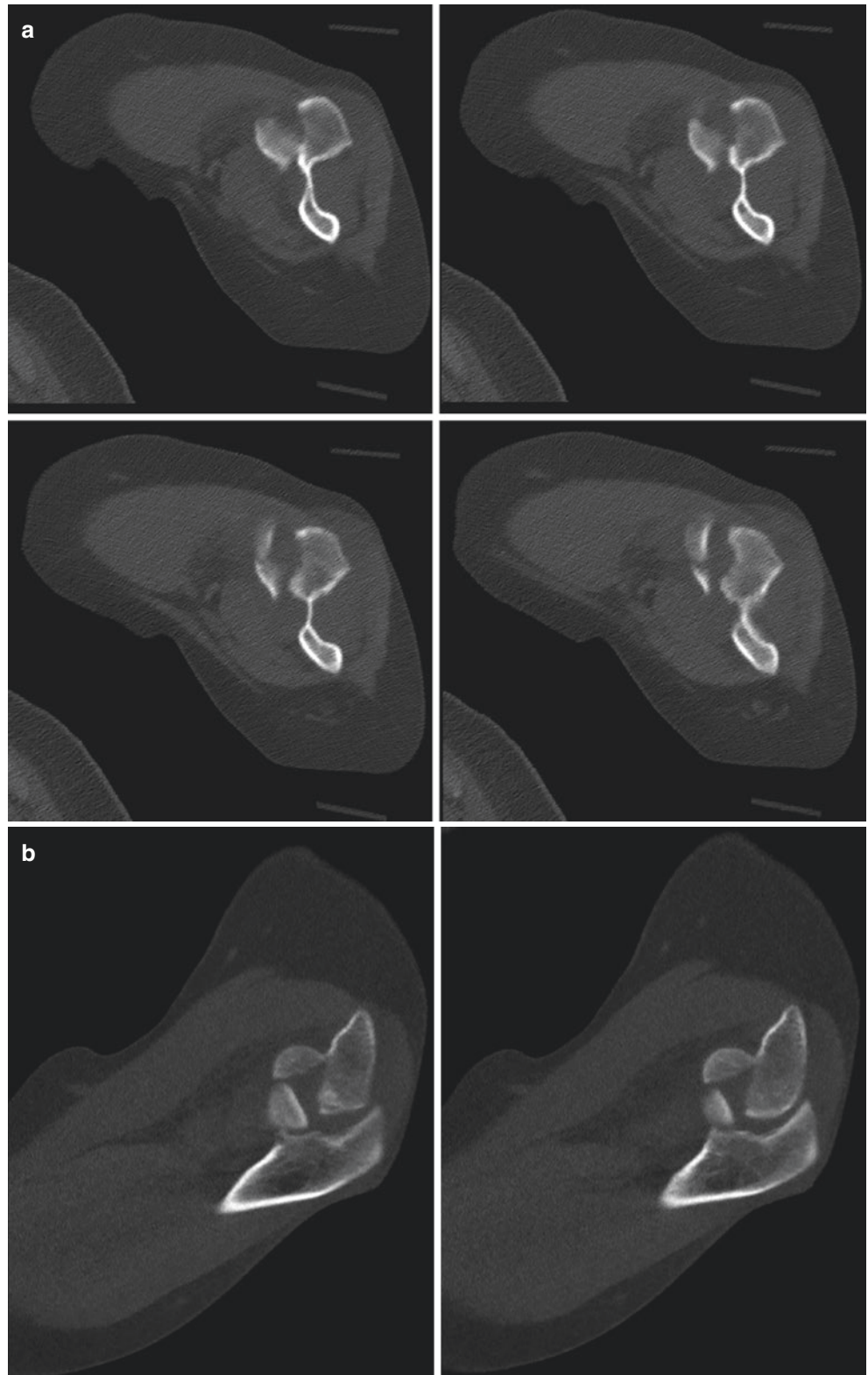
Almost invariably, the anterior shear fracture of the distal humerus is approached from a lateral supracondylar vantage

point, elevating the mobile wad origin. Critical to the approach is knowing that a portion of the posterior lateral column is intact to allow reduction and fixation to the constant, stable posterolateral column. The CT scan is helpful in the evaluation, because if the posterior aspect is involved, the approach may be changed to a posterior approach with an olecranon osteotomy technique (Figs. 15.1, 15.2, 15.3, and 15.4).

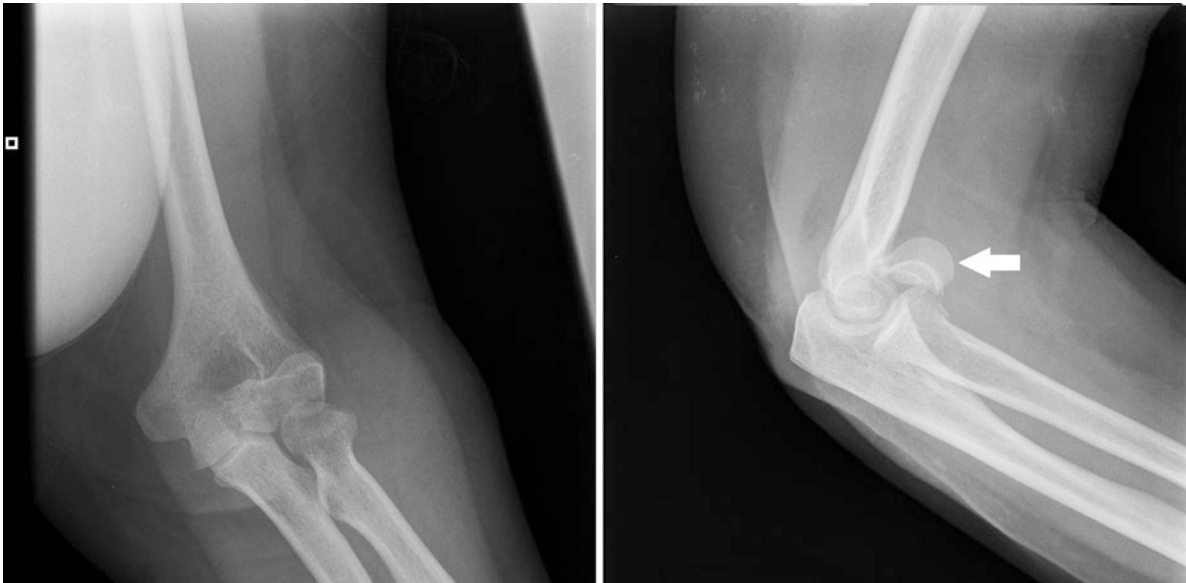


**Fig. 15.1** Injury radiographs of left capitellum fracture

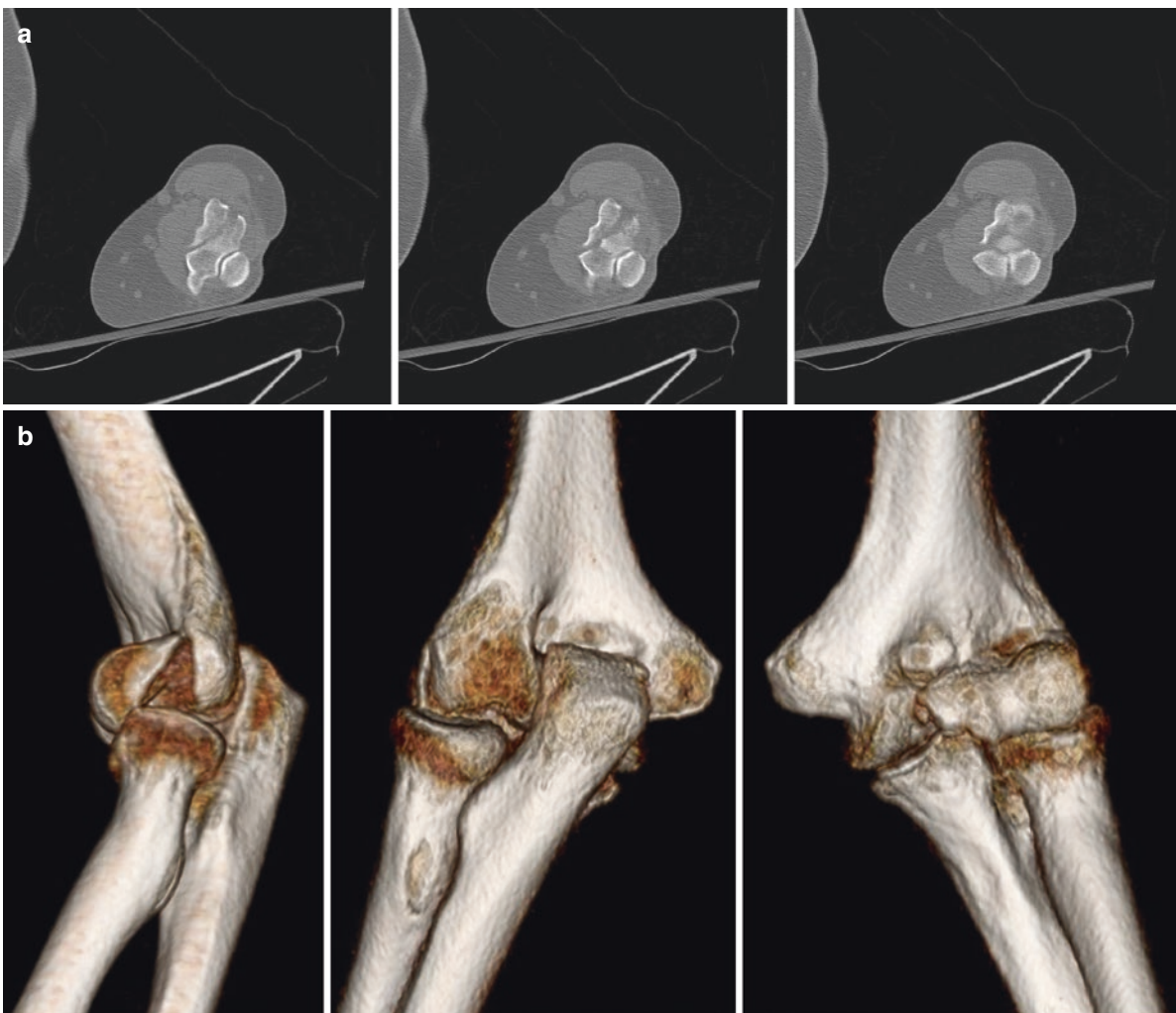
**Fig. 15.2** (a) Axial CT scan of left distal humerus, revealing capitellum fragment with medial extension into the trochlea and stable posterior cortex. (b) Sagittal CT scan revealing the displaced capitellum





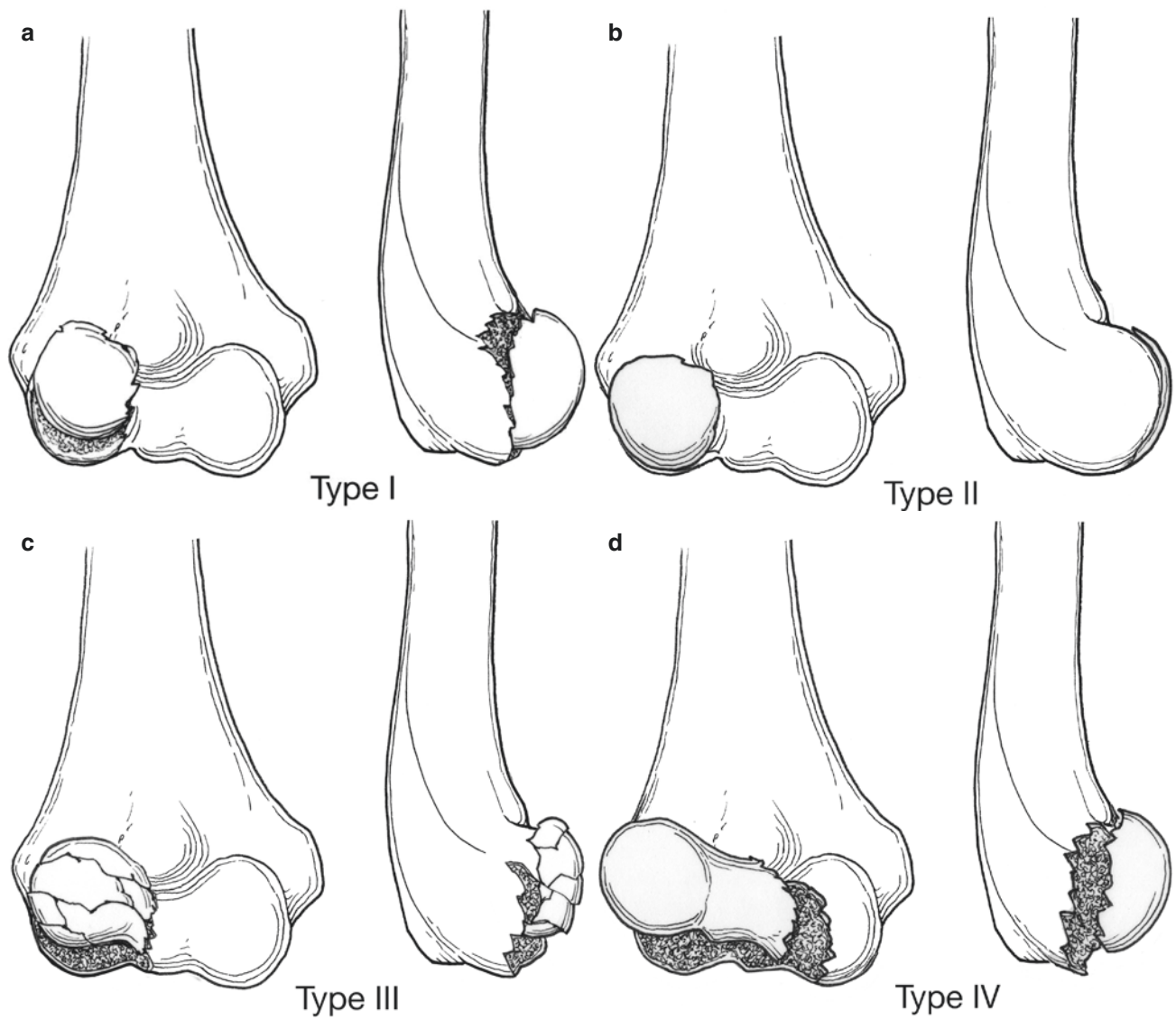


**Fig. 15.3** Radiographs of left distal humerus with capitellum and lateral trochlea fracture with double crescent sign (*arrow*)



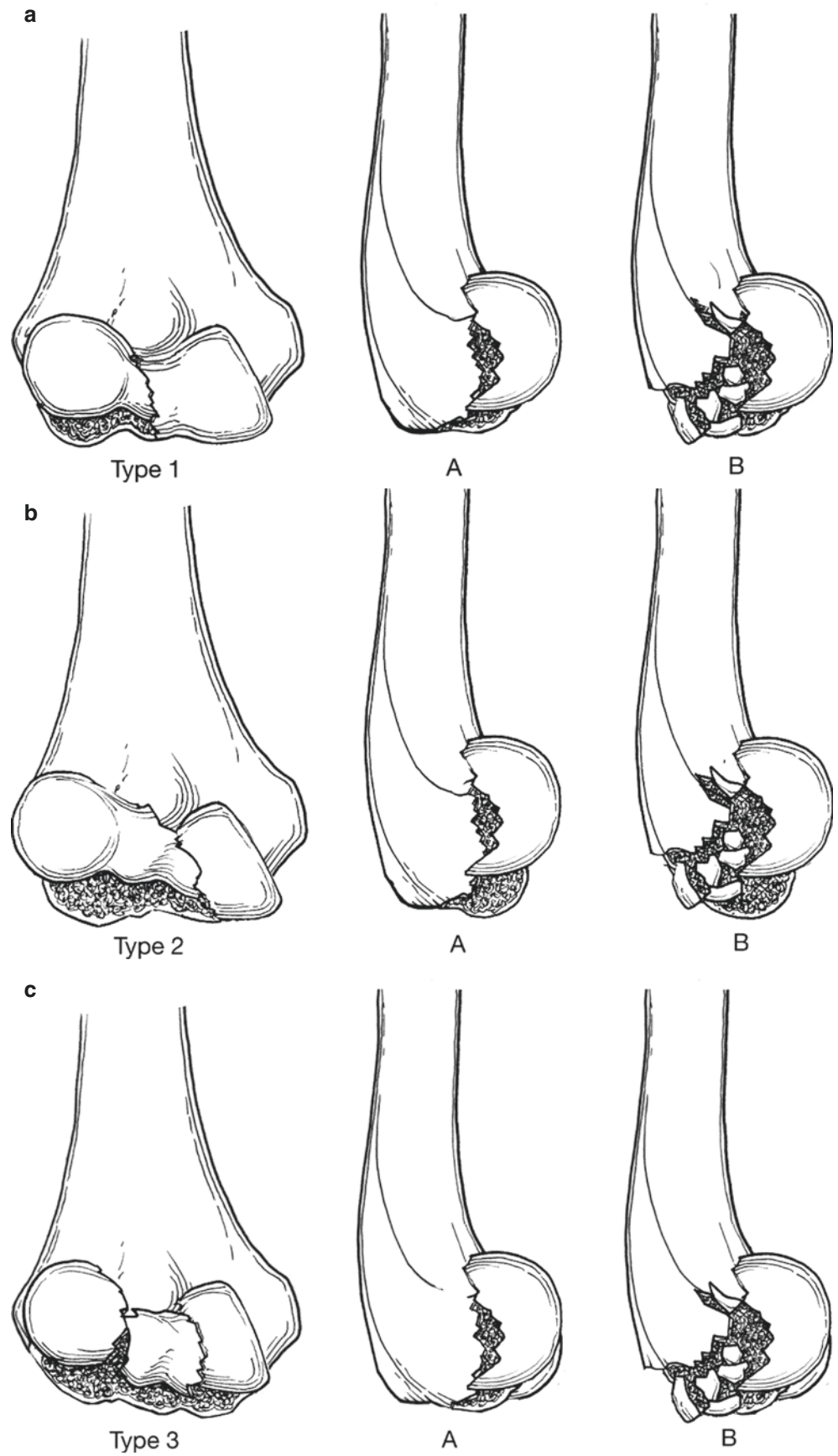
**Fig. 15.4** (a) Axial CT scan of left distal humerus and capitellum with medial extension and intact posterior cortex. (b) Three-dimensional (3D) CT scan of distal humerus

Classification systems have been proposed, including those of Bryan and Morrey [6] (Fig. 15.5), Dubberley *et al.* [3] (Fig. 15.6), and Ring *et al.* [2] (Fig. 15.7) [1, 7].

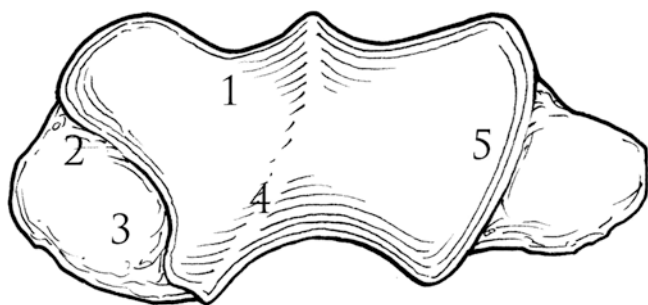


**Fig. 15.5** Bryan and Morrey classification. (a) Type I. (b) Type II. (c) Type III. (d) Type IV (added by McKee *et al.* [6])

**Fig. 15.6** Dubberley classification. (a) Type 1. (b) Type 2. (c) Type 3







**Fig. 15.7** Ring classification

Regardless of classification, these systems provide little guidance other than that the worse fractures, with more posterior, medial extension, require a more extensile approach and exposure, including an olecranon osteotomy. But aren't these fractures more like a T-intercondylar fracture anyway? I digress. Let's continue to focus on the true anterior shear fractures.

A review at Shock Trauma shows that over a 10-year period, we treated 17 anterior shear fractures: 16 anterior and one posterior. Of those, 15 had capitellar and trochlear involvement; none was a pure capitellar fracture. Two fractures were medial trochlea shear fractures. Thus, most of the anterior shear fractures would be classified by Bryan and

Morrey as modified Type IV. I'm sure that isolated capitellar fractures exist, but apparently they tend not to be referred to us for treatment.

## 15.2 Patient Setup and Surgical Approach

The lateral approach, along the supracondylar ridge and distal and anterior to the lateral ligamentous complex and annular ligaments, allows access to the joint. I avoid using the term *radial collateral ligament* because of controversy about its existence.

Setup prepping and draping is performed in such a way that the patient's elbow falls in the center of the hand table, with a sterile tourniquet utilized so that the drapes don't block the surgical site. This setup is used for any elbow intervention. The arm will come across the chest only for the intramedullary ulna screw. I do not use lateral patient positioning for fractures distal to the T-intercondylar fractures because I find looking into the joint anteriorly is easier from the lateral approach, as opposed to the upside-down approach. The setup, prepping, and draping demonstrated in this chapter can be referred to for any procedure in the following chapters involving the elbow (Figs. 15.8, 15.9, 15.10, 15.11, 15.12, 15.13, 15.14, 15.15, 15.16, 15.17, 15.18, 15.19, 15.20, 15.21, 15.22, 15.23, 15.24, 15.25, and 15.26).



**Fig. 15.8** Prep and drape for elbow approach with sterile tourniquet. The hand table is positioned so that the elbow falls in middle of the table when flexed at 90° and resting on a bump



**Fig. 15.9** Arm suspended



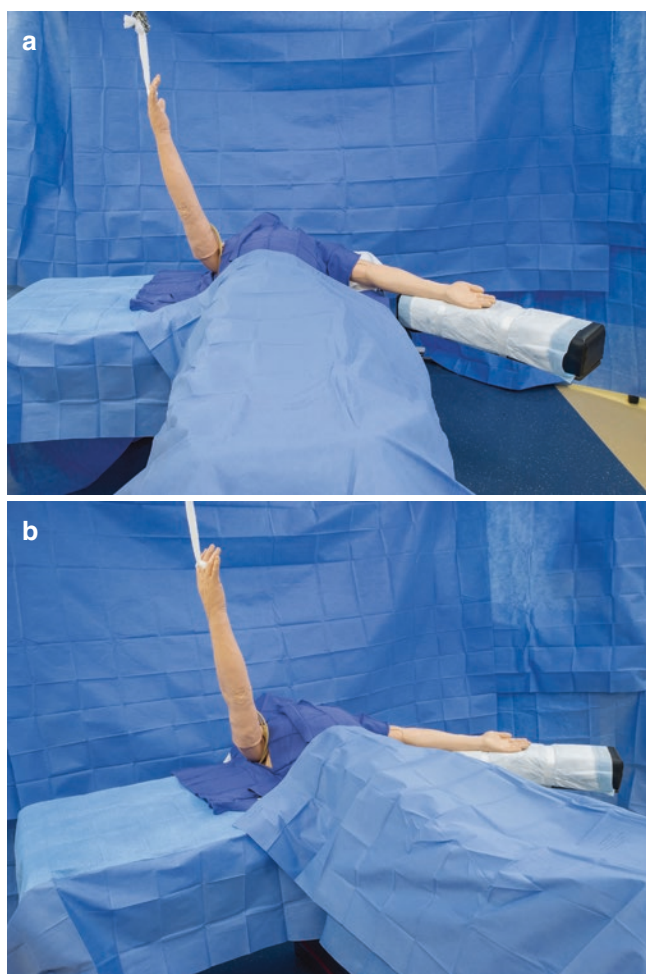
**Fig. 15.10** Absorbent barrier on hand table, with impervious drape arched over shoulder



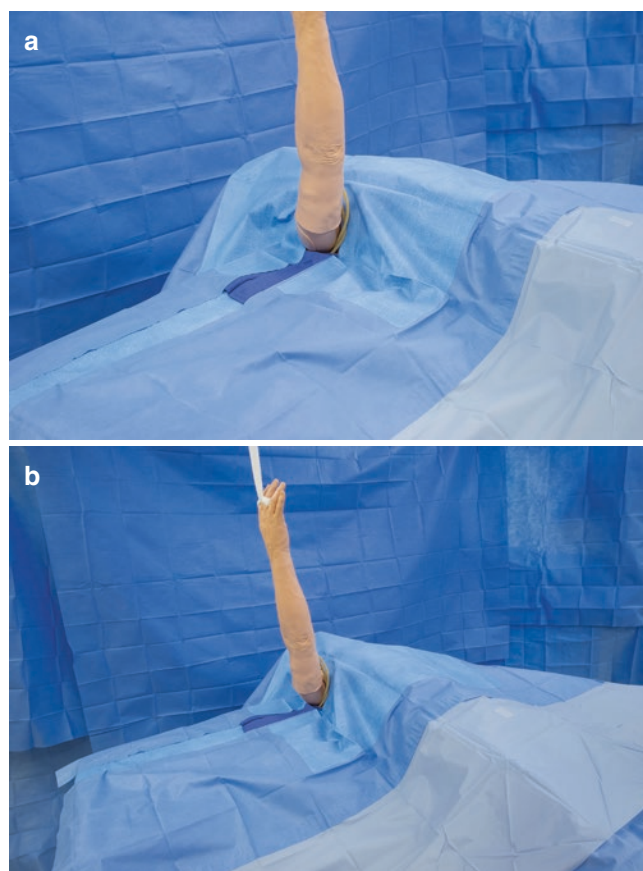
**Fig. 15.11** Two more barriers are over the chest. Note no impervious barriers under shoulder, and absorbent barrier only to absorb prep and prevent puddling



**Fig. 15.12** Body drape first



**Fig. 15.13** (a, b) Three-fourths reinforced sheet on hand table, followed by three towels in triangle around shoulder

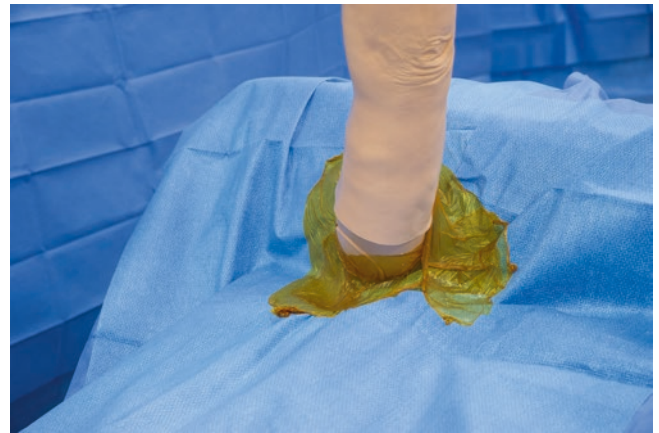


**Fig. 15.14** (a, b) Split drape, tails down. Note that the drapes are unfolded and smooth

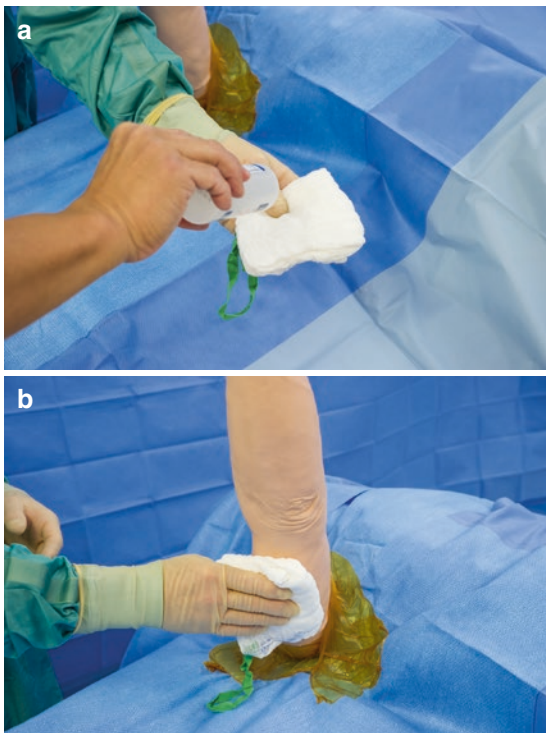




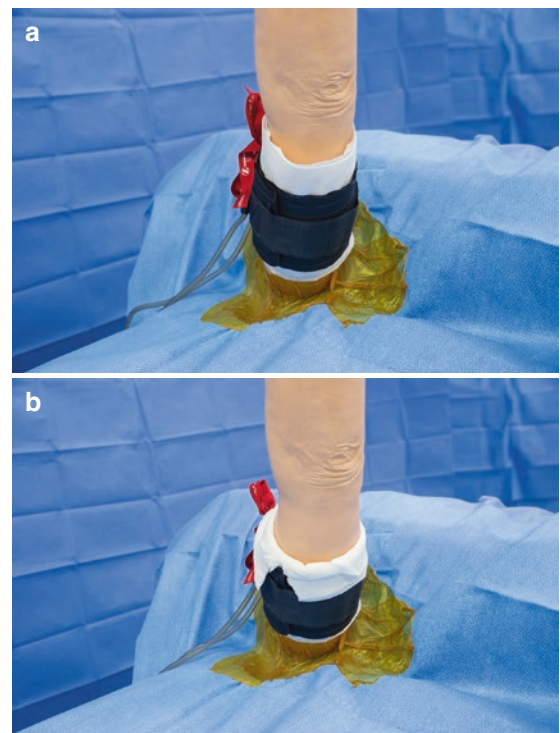
**Fig. 15.15** Split drape, tails up



**Fig. 15.16** Loban® strips around splits to seal to arm. Apply Ioban® prior to alcohol so the Ioban® sticks



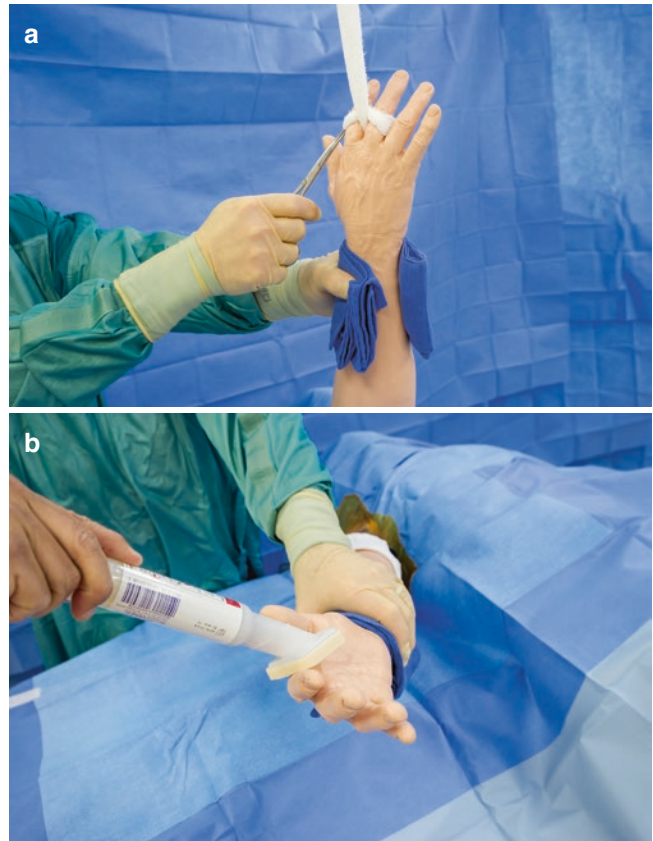
**Fig. 15.17** (a, b) Alcohol on sponge to wipe Betadine prep off arm prior to tourniquet application, to prevent Betadine burns under the tourniquet



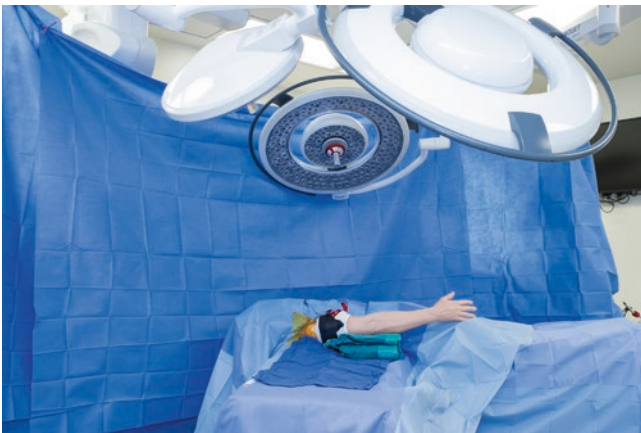
**Fig. 15.18** (a, b) Six-inch sterile Webril™ padding with tourniquet applied for hoses to fall over the shoulder, not across the chest. The Webril™ is split and turned over the tourniquet to prevent migration



**Fig. 15.19** Do not cross the chest, because of potential need for access to the chest in a trauma patient



**Fig. 15.20** (a, b) Hand down, finger painted



**Fig. 15.21** Arm positioned on bumps, lights positioned over end of table. (*Note:* The elbow is normally flexed, but the mannequin's elbow doesn't flex)

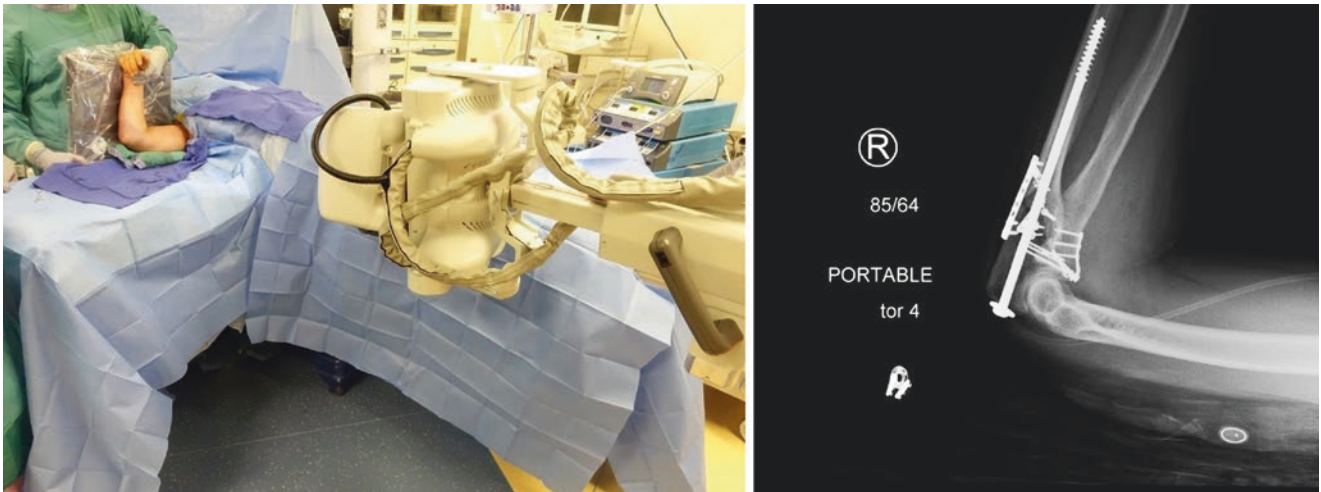


**Fig. 15.22** Do not put lights behind the surgeon's head



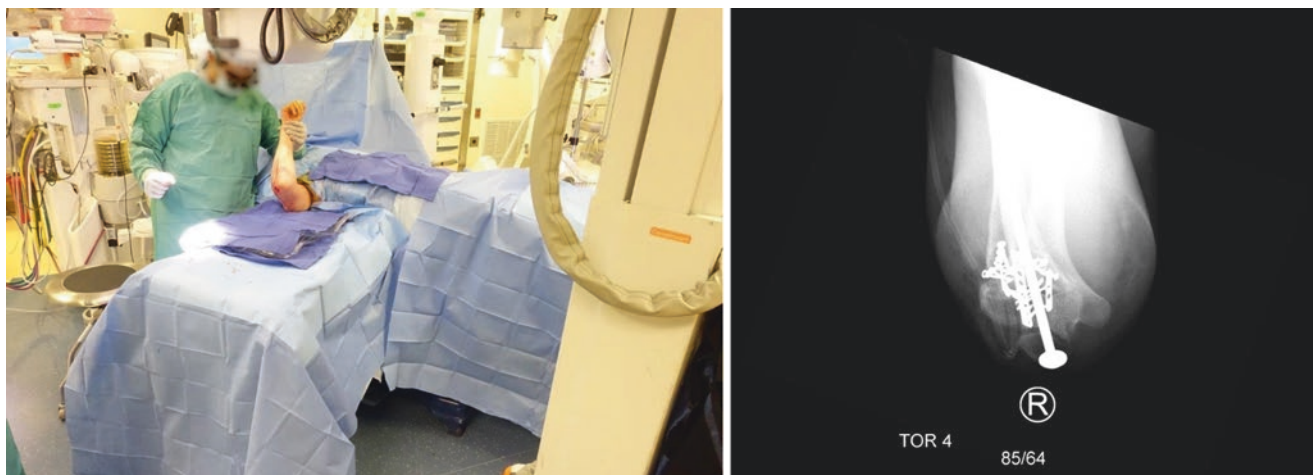


**Fig. 15.23** Radiographs of olecranon process fracture utilized for purposes of positioning for radiographs



**Fig. 15.24** Cross table lateral; note three-quarter sheet on body to allow head of the machine to position next to the patient, followed by removal after film is obtained





**Fig. 15.25** Cubital tunnel view (or “Harris-Beath” view) of the elbow

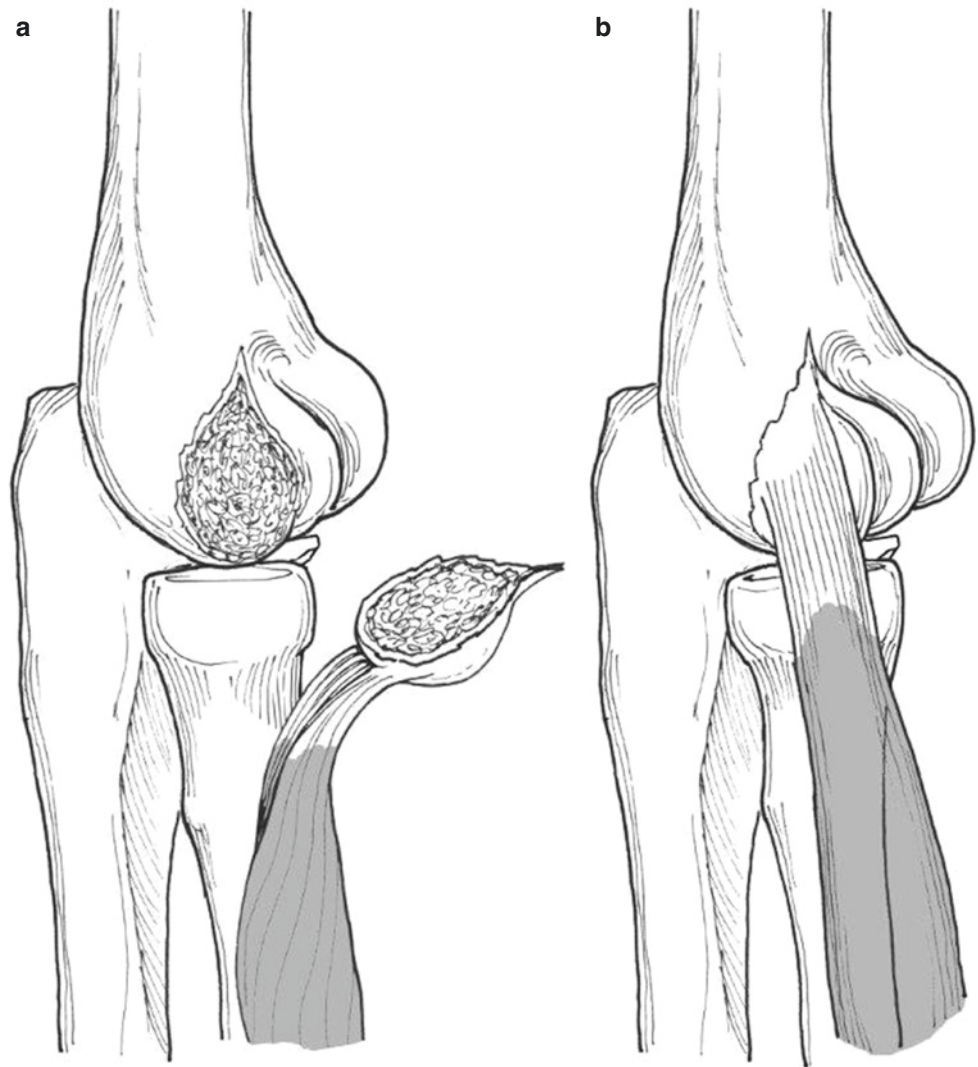


**Fig. 15.26** Anterior posterior projection with machine from the opposite side so as not to extend the elbow, particularly if there has been coronoid process fixation

### 15.3 Fracture Reduction and Fixation Procedure

I tell our Shock Trauma residents that there are three problems with open reduction and internal fixation (ORIF) of the

fracture: getting to the fracture, reducing it, and getting fixation. Sometimes the capitellar fragment is rotated 180° with the extensor carpi radialis brevis origin still attached. If the fragment is derotated, the soft tissues tend to block visualization during reduction (Fig. 15.27).



**Fig. 15.27** (a) Rotated capitellum fragment with extensor carpi radialis brevis (ECRB) attachment. (b) Fragment reduced, blocking visualization of reduction and access for fixation

Fortunately, in this scenario a metaphyseal extension proximal to the capitellum normally can be used as a reduction key for fixation. If the lateral collateral ligament complex is attached to the stable supracondylar ridge, and there is not a fracture fragment, I frequently osteotomize the epicondyle, which allows better access to the joint (Fig. 15.28).



**Fig. 15.28** Intraoperative radiograph of osteotomized fragment (arrow) rotated to allow access to the joint

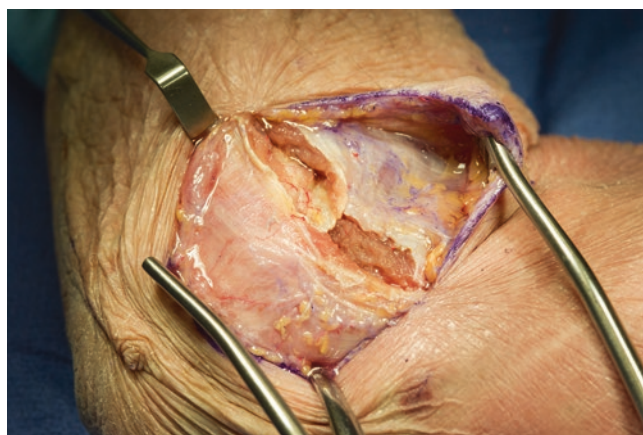
Once reduction is attained, Kirschner wires (K-wires) are used for provisional fixation and possibly for definitive fixation (Figs. 15.29, 15.30, 15.31, 15.32, 15.33, 15.34, 15.35, 15.36, 15.37, 15.38, 15.39, 15.40, 15.41, 15.42, and 15.43).



**Fig. 15.29** Incision is centered over the lateral epicondyle, along the supracondylar ridge (shoulder to *right*) and distally (hand is *up*), as needed for access to the radiocapitellar joint



**Fig. 15.30** Skin incision with exposure of epicondyle



**Fig. 15.31** Anterior incision of wrist extensors origin with elevation off the supracondylar ridge

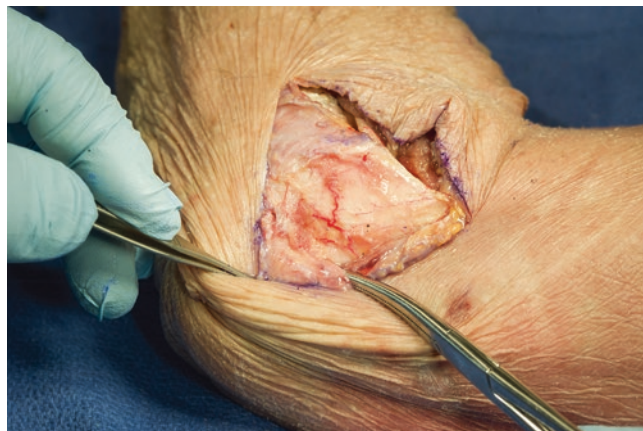


**Fig. 15.32** ECRB deep fascia in pickups

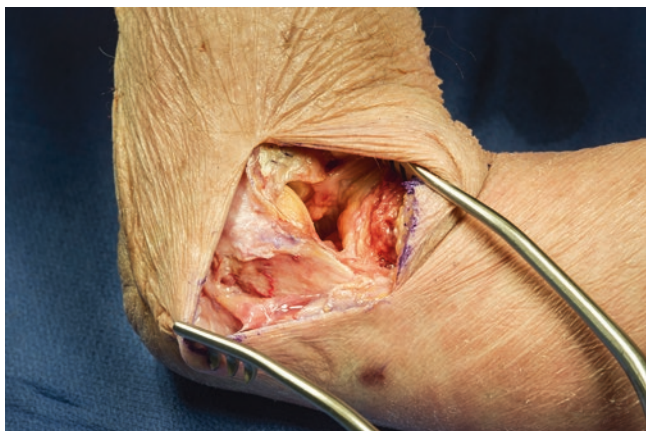




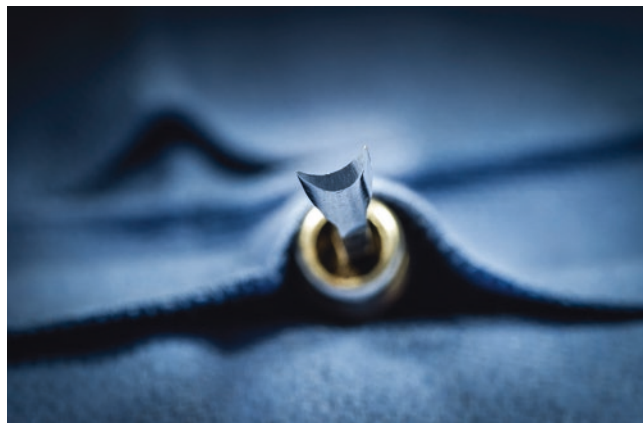
**Fig. 15.33** Proximal division of annular ligament to allow radiocapitellar joint visualization



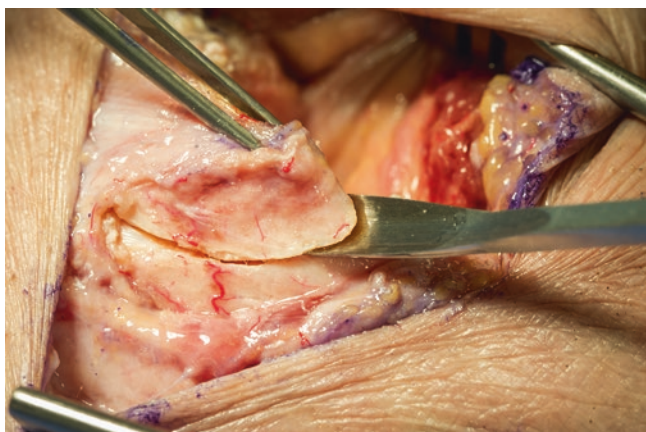
**Fig. 15.34** Posterior approach between anconeus and triceps, exposing the middle radial collateral vessels on the lateral column posterior to the capitellum



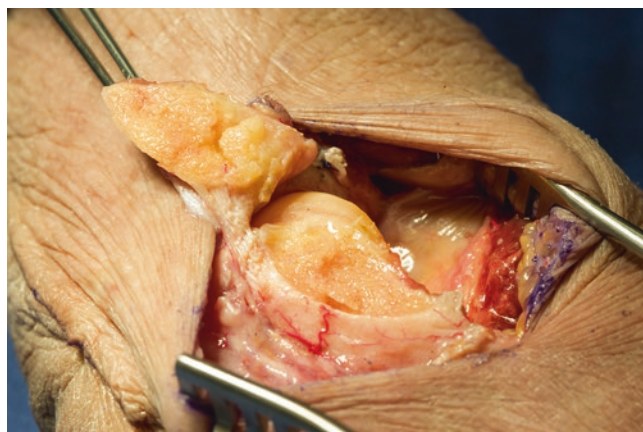
**Fig. 15.35** Anterior and posterior exposure



**Fig. 15.36** If a lateral epicondyle osteotomy is selected, using a sharp, curved gauge makes a trough for fragment reduction

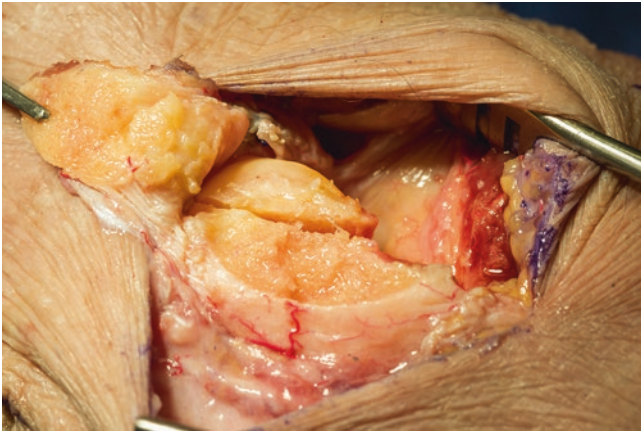


**Fig. 15.37** Performing the osteotomy; notice stress risers posteriorly

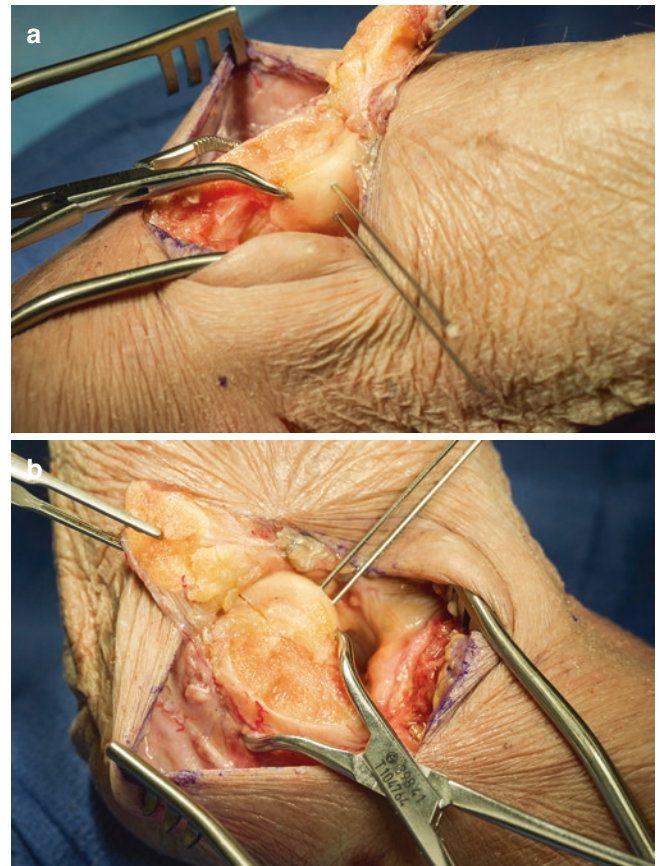


**Fig. 15.38** Reflected fragment with ligamentous attachments

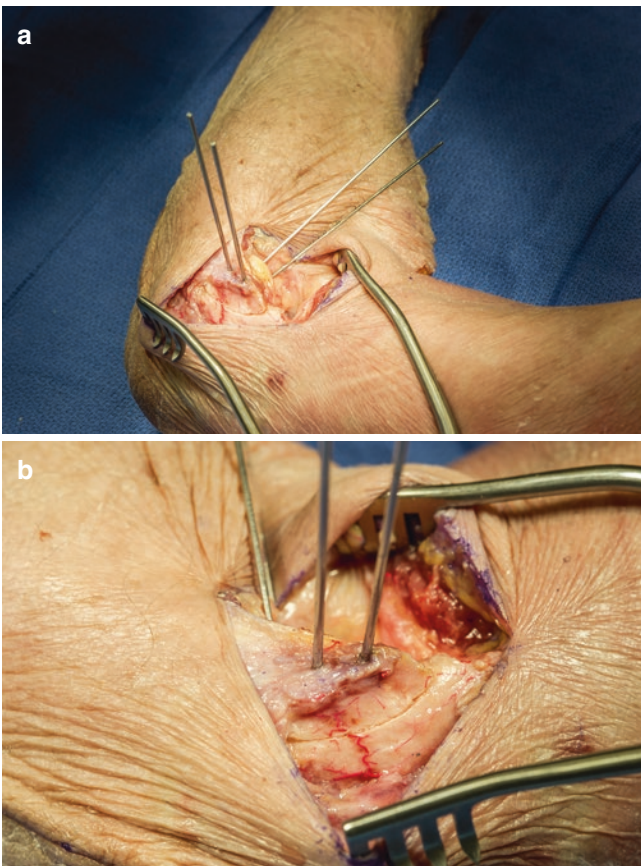




**Fig. 15.39** Osteotomized (fractured) capitellum



**Fig. 15.40** (a) Reduction performed, held with two 0.045-inch Kirschner wires (K-wires). (b) Headless screws would be inserted at this point, with a possible buttress plate at the proximal metaphyseal extension of the capitellum, using another 1.5-mm or 2.0-mm plate



**Fig. 15.41** (a) Lateral epicondyle reduced and held with two K-wires. (b) A 2.4-mm or 2.7-mm mini-fragment locking plate would be placed over these K-wires sequentially removed



**Fig. 15.42** Injury radiographs of case in Fig. 15.28

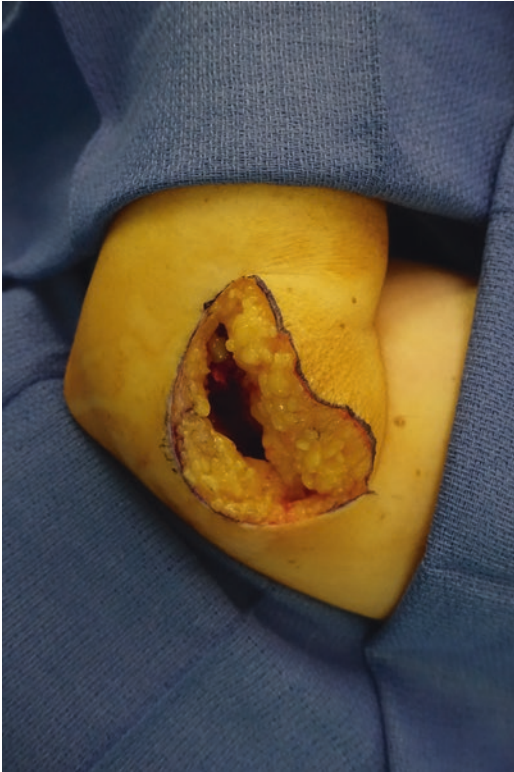


**Fig. 15.43** Radiographs following open reduction and internal fixation (ORIF) of the capitellum via an epicondyle osteotomy



If a headless screw system is used, I recommend a threaded-tip guide wire, which needs to be placed in either the anteroposterior or lateromedial orientation, followed by

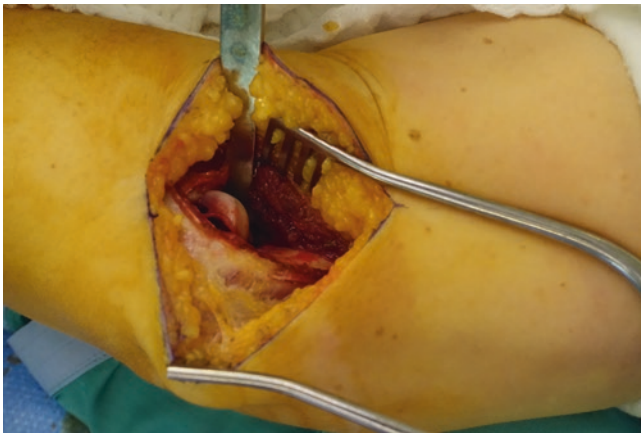
screw insertion. I prefer anterior/posterior (AP) headless screws (Synthes® 2.4-mm or 3.0-mm) for fixation (Figs. 15.44, 15.45, 15.46, 15.47, and 15.48).



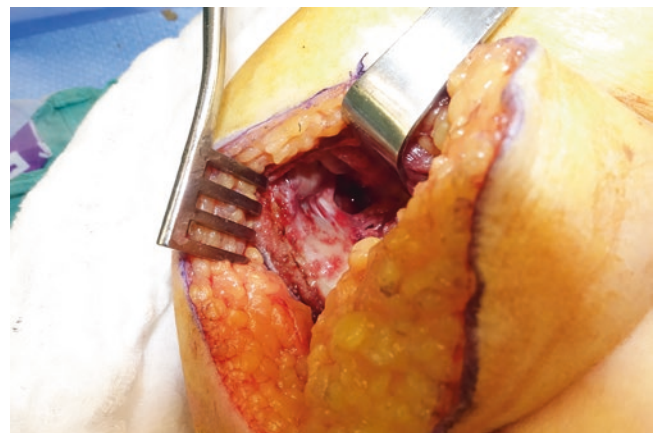
**Fig. 15.44** Lateral approach and exposure of case in Fig. 15.1



**Fig. 15.46** Reduced capitellum from lateral view



**Fig. 15.45** Displaced capitellum perched on radial head



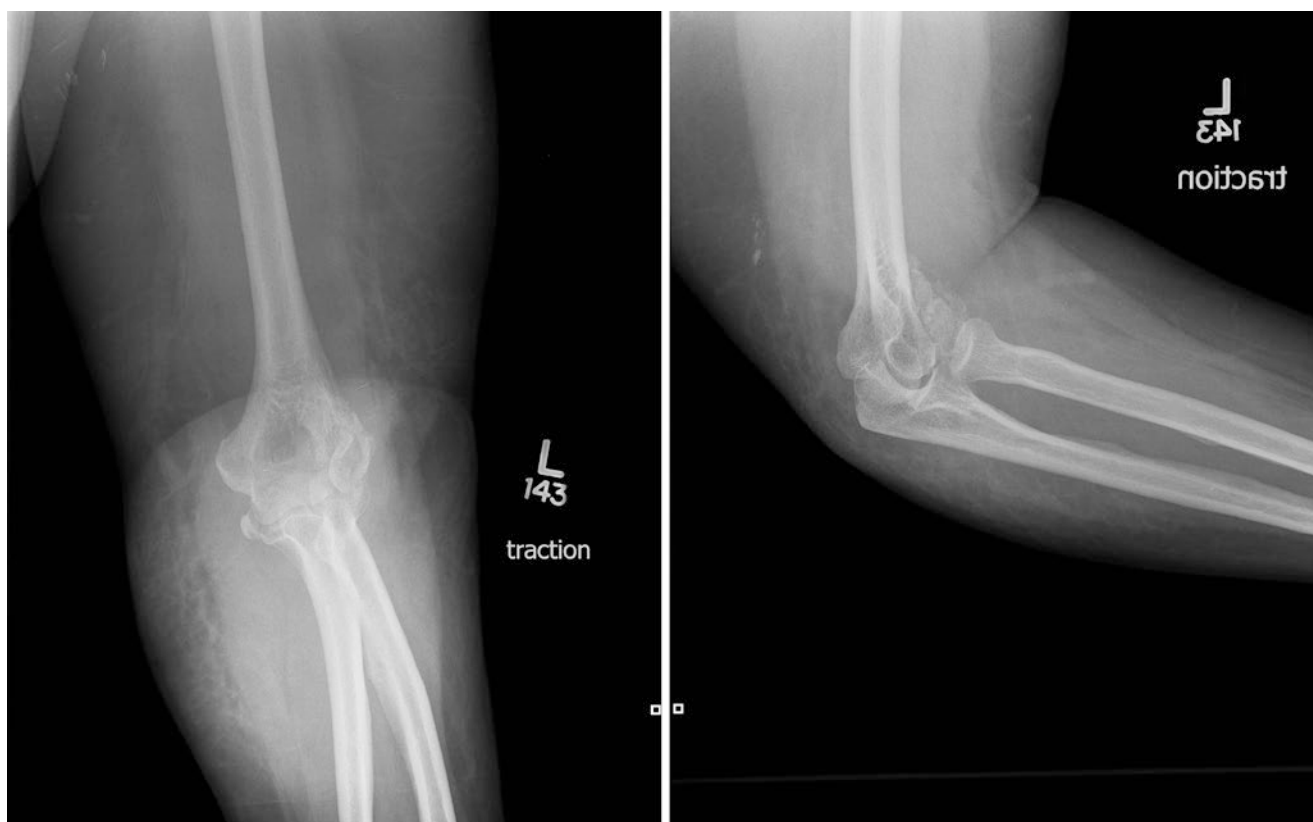
**Fig. 15.47** Reduced capitellum from anterolateral view



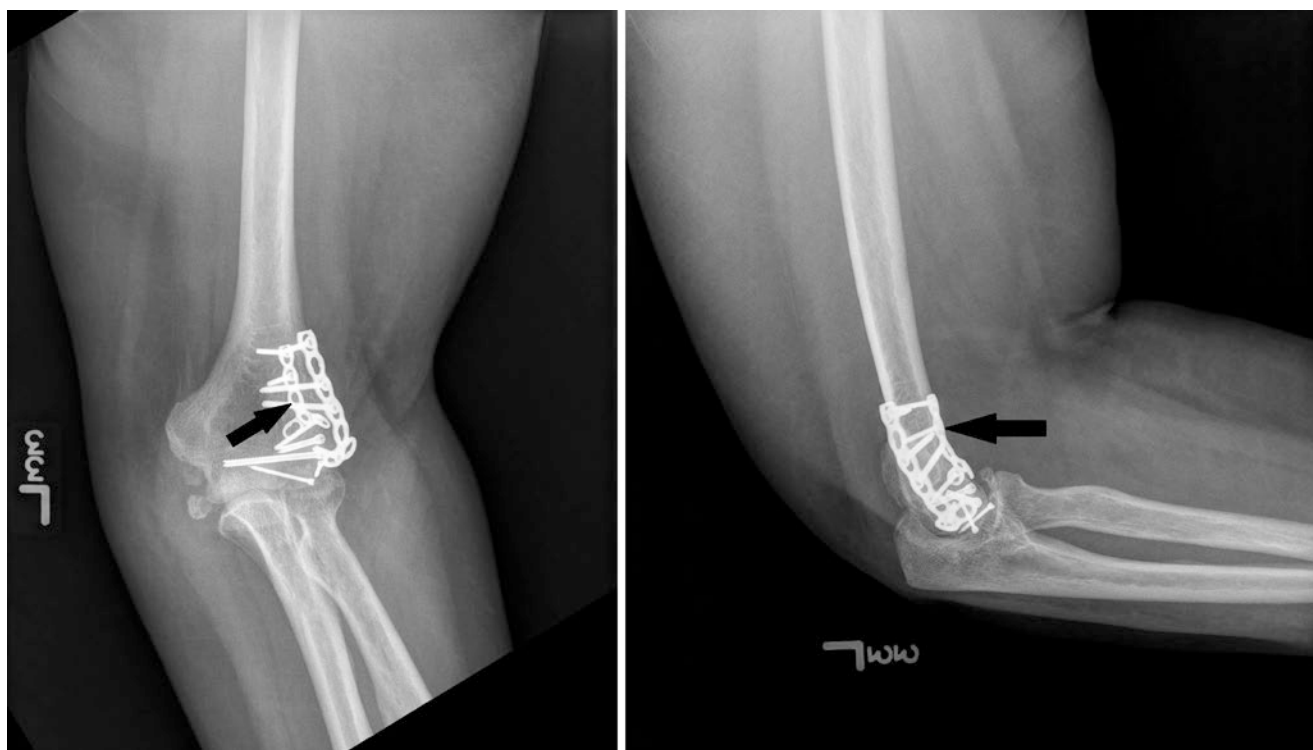
**Fig. 15.48** Radiographs following ORIF with headless screws, in an anterior-to-posterior direction

Biomechanical studies compare AP to PA cancellous screws, as well as to AP headless screws [8]. Screw types also have been studied [9]. The PA cancellous screw is reportedly superior to the AP, and the PA cancellous screw is roughly equivalent to the Acutrac® screw, which was superior to the Herbert® screw.

Because it is difficult to place the guide wires and sense the opposite cortex, and then to determine screw length, I put in the guide wire, over-drill, then use a depth gauge before placing a new wire into the previously drilled hole. Then I place a cannulated screw. If the metaphyseal extension is in the capitellar fragment, I use a 1.5-mm or 2.0-mm T-type plate in buttress mode (Figs. 15.49, 15.50, and 15.51).



**Fig. 15.49** Injury radiographs of left capitellum fracture



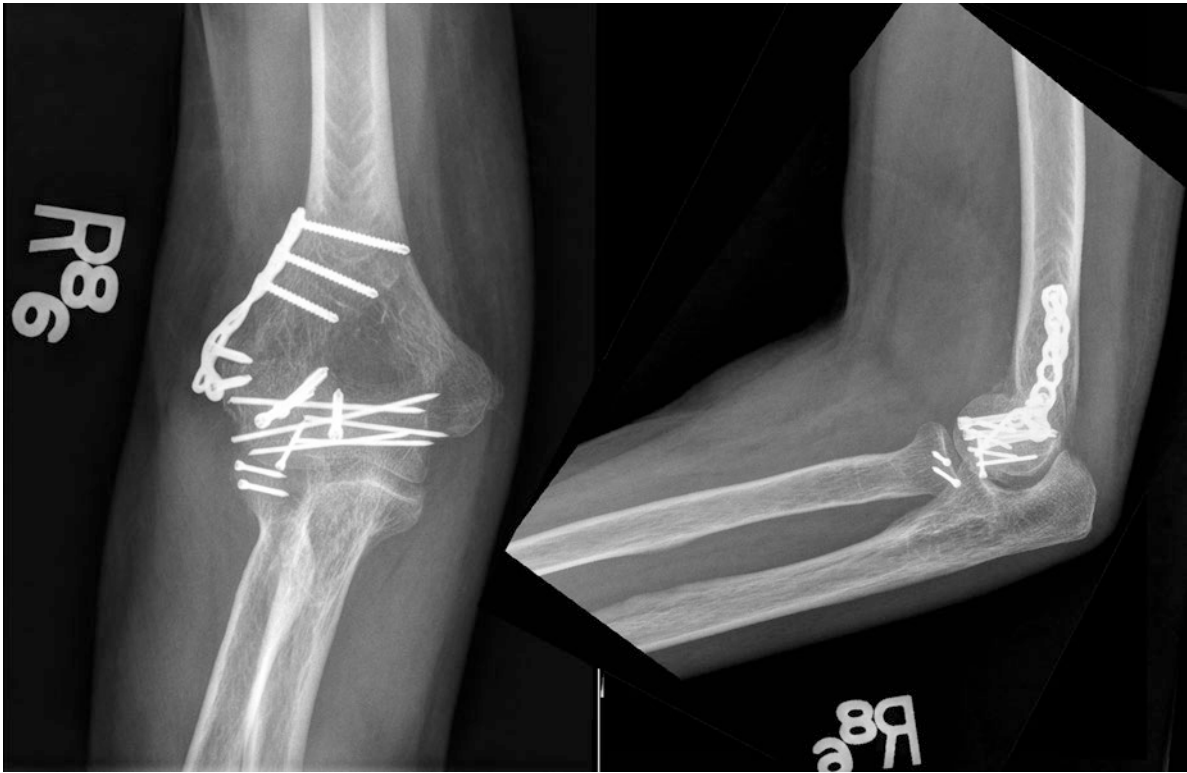
**Fig. 15.50** Radiographs following ORIF including plate (*arrow*) in buttress mode at capitellum metaphyseal fragment





**Fig. 15.51** Another example of a mini-fragment plate buttressing against the capitellum and metaphyseal extension

Typically, I put the epicondyle osteotomy back with a contoured 2.4-mm locking mini T-plate with a significant anterior sagittal bend, and approximately a 90° bend to the T in order to secure the osteotomized fragment (Fig. 15.52).



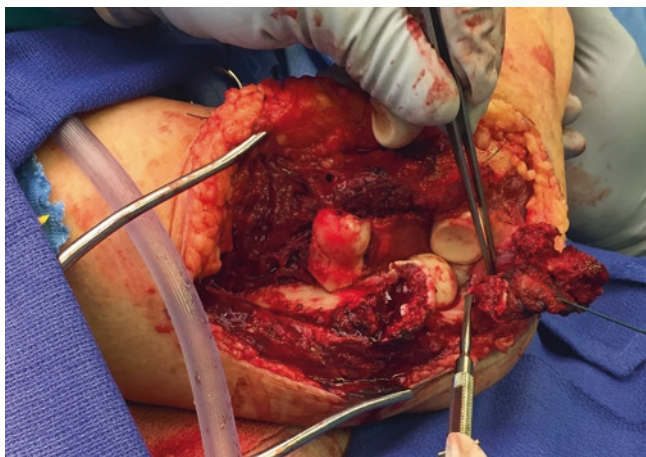
**Fig. 15.52** Epicondyle fixation with significant contouring of a mini-fragment locking plate

It also is critical to prevent the elbow from extending during closure, as there can be a tendency for the radial head to engage

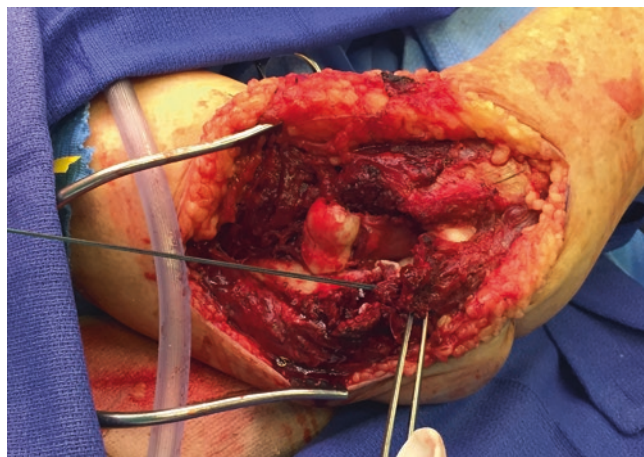
the reduced fragment, which will apply a proximal shearing force that recreates the injury (Figs. 15.53, 15.54, 15.55 and 15.56).



**Fig. 15.53** Traction radiographs of right elbow anterior shear fracture; note the double crescent sign (*arrow*)



**Fig. 15.54** Intraoperative fracture preparation for ORIF and ligament repair, with pickups pointing to the posterior capitellum fragment, utilizing a lateral approach



**Fig. 15.55** Lateral collateral ligament (LCL) sutures tensioned (*Case courtesy of Dr. Raymond Pensy*)





**Fig. 15.56** Follow-up radiograph following ORIF. This patient was casted because of compliance concern

After closure, a long arm splint at 90° is applied, with the wrist in extension and the forearm in slight pronation.

## 15.4 Patient Rehabilitation

Therapy and motion begins on the patient's first postoperative visit. Full flexion is permitted, but extension is limited to 15° short of the radial head engaging the capitellum fracture line posteriorly. This is determined intraoperatively. Generally, I limit the extension for approximately 4 weeks. Full pronation and supination is allowed, with the elbow at 90°. Night splinting is continued for 6 weeks. Strengthening begins at 6 weeks and weight-bearing usually begins at 3 months.

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## 16.1 Fixation Options for Olecranon Fractures

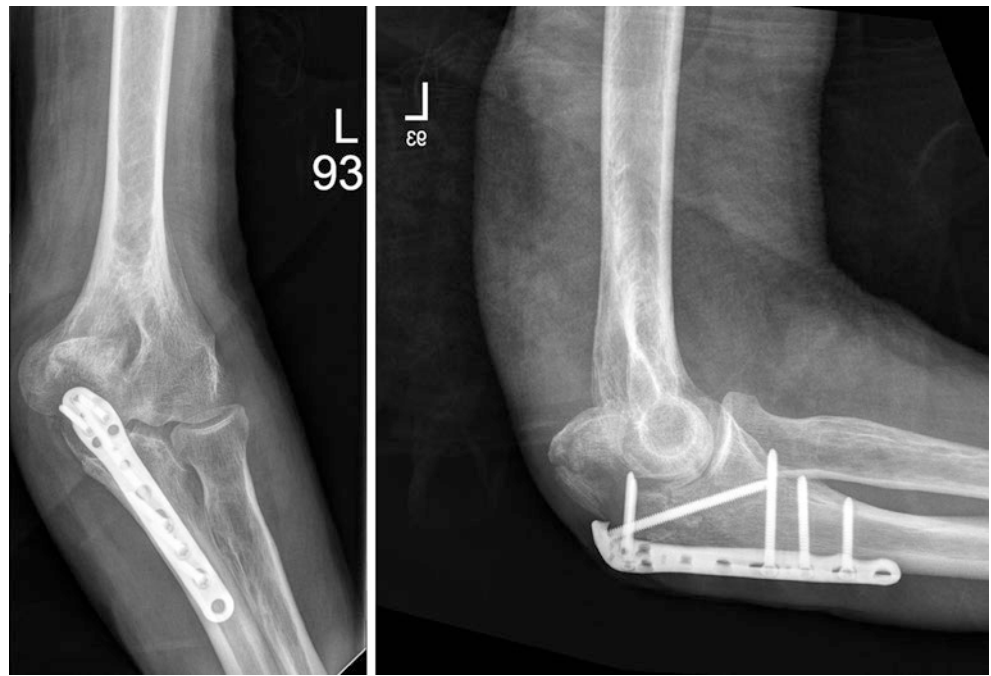
What is the infatuation with plate fixation for olecranon fractures? Why the desire to use a device both expensive and bulky, which tends to displace fractures because of its non-

anatomic design? This choice is intriguing to me, when other options are available (Figs. 16.1, 16.2, 16.3, 16.4, 16.5, and 16.6).



**Fig. 16.1** (a–c) Radiographs of left elbow following open reduction and internal fixation (ORIF) of olecranon process fracture with proximal ulna plate coursing laterally

**Fig. 16.2** Radiographs on presentation following ORIF of the left olecranon process fracture with loss of fixation of proximal fragment



**Fig. 16.3** Radiographs following revision ORIF with tension band, K-wire construct



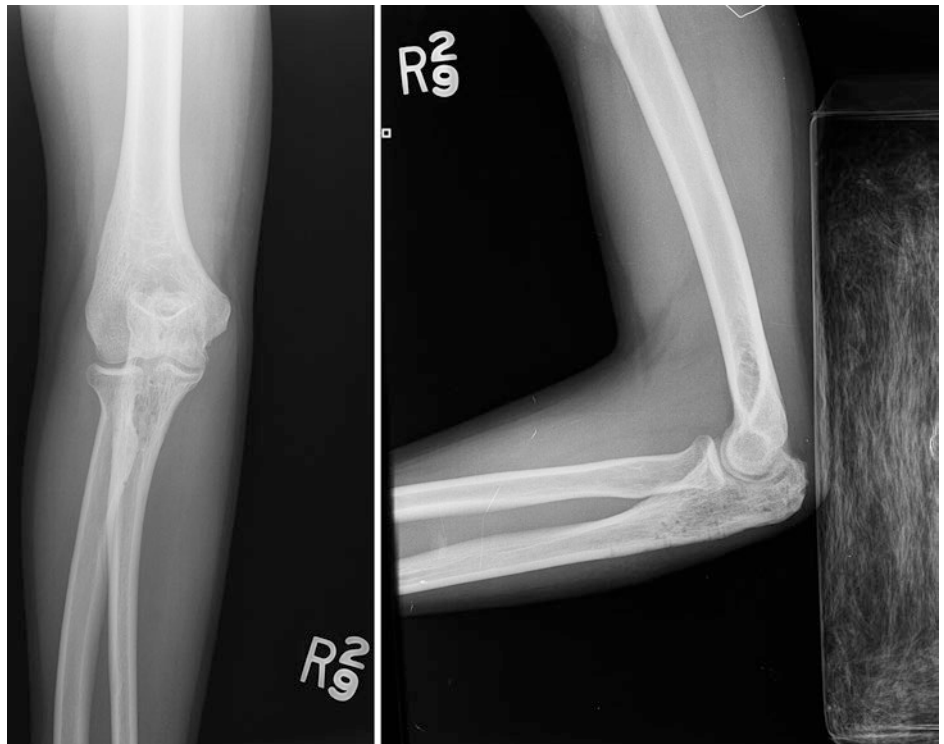
**Fig. 16.4** Radiographs on presentation following transfer from an outside hospital with internal fixation with a reconstruction plate but without joint reduction



**Fig. 16.5** Radiographs following revision ORIF with mini-fragment plates and tension band construct



**Fig. 16.6** Radiographs after hardware removal at the request of the patient



I realize that the plate examples I have presented reflect a small percentage of olecranon processes undergoing open reduction internal fixation (ORIF); many patients do have a good result. I also realize that some of the problems with the plates may be secondary to technique. Everything I touch doesn't turn to gold.

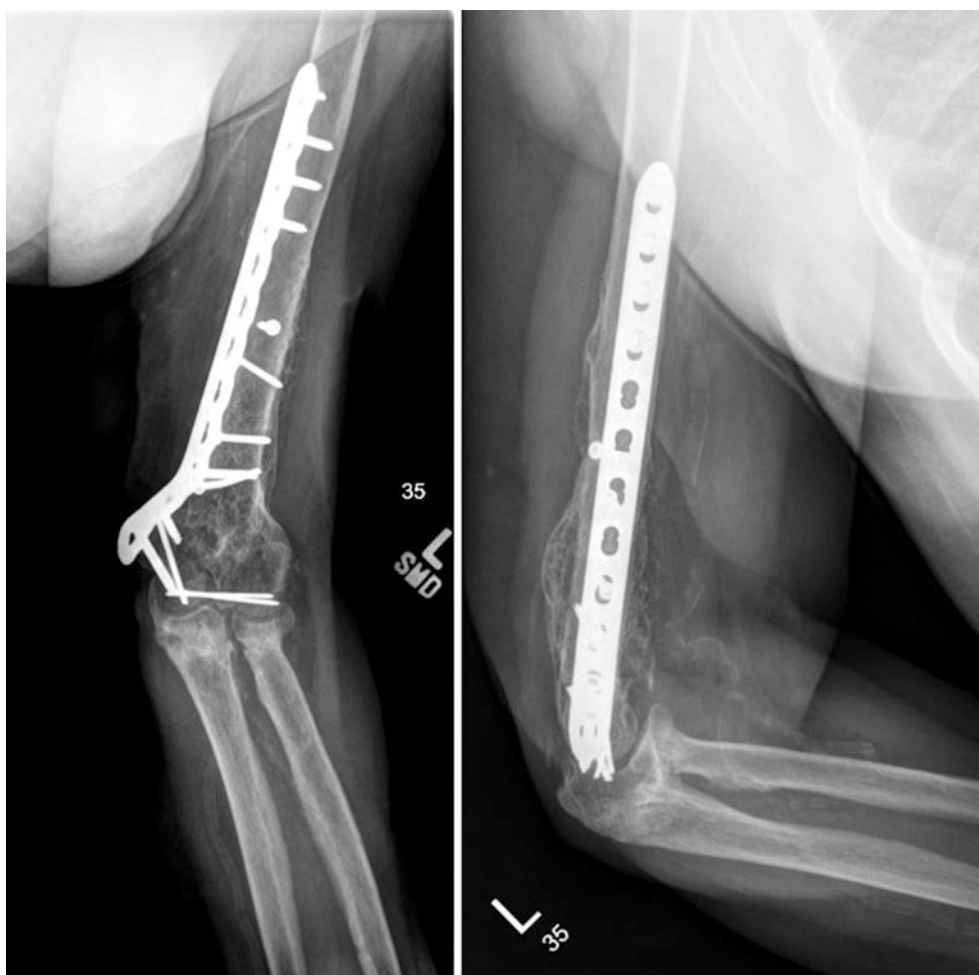
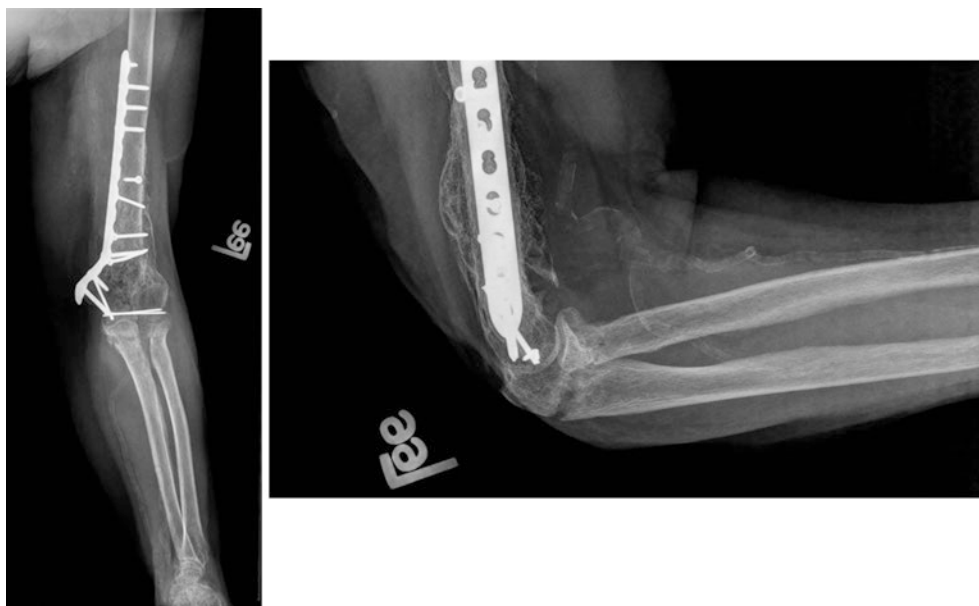
But we make a leap in faith when we jump right to operative intervention; other options are available. Even with displaced fractures—particularly in the elderly—I have used nonoperative treatment, and it has been reported in the literature (Figs. 16.7, 16.8, 16.9, and 16.10) [1, 2].



**Fig. 16.7** Fracture of left olecranon process



**Fig. 16.8** Closed treatment in splint

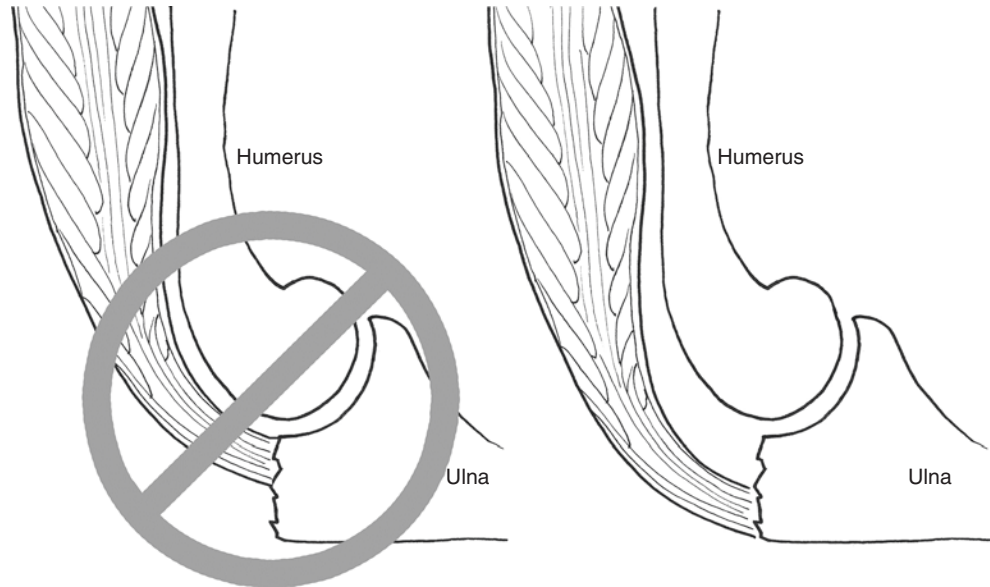
**Fig. 16.9** Interval healing**Fig. 16.10** Healed olecranon



Fragment excision and triceps advancement has been reported in a number of cases, with a decreased incidence of complications [3–5]. Olecranon fragment excision is associated with the loss of flexion and a nearly linear proportional

decrease in elbow stability [6, 7]. The proper positioning of the triceps is important. To improve extension strength, the triceps should be inserted dorsally and not adjacent to the joint (Fig. 16.11) [8, 9].

**Fig. 16.11** Correct dorsal insertion of triceps tendon into the olecranon



When fixing an avulsion injury of the triceps, I have been happy to get the triceps securely reinserted, as the tendon seemed to cover most of the tip of the olecranon anyway. I

have personally used excision of the olecranon and reinsertion only once, in a failed olecranon osteotomy that required triceps advancement (Fig. 16.12).



**Fig. 16.12** Radiographs of left elbow following numerous surgeries for open left distal humerus fracture with olecranon nonunion excision and triceps advancement

### 16.1.1 K-Wires and Tension Band, 6.5-mm Screws

The frequently maligned Kirschner wires (K-wires) and tension band, or the underappreciated and seldom-used 6.5-mm

screws are attractive options for olecranon fracture fixation. The issue concerning the tension band wires emanates again from the concept that K-wires tend to back out, whereas the issue in fact is probably more that the K-wires were initially not adequately inserted (Figs. 16.13 and 16.14) [10].

**Fig. 16.13** Injury radiographs of comminuted right olecranon fracture



**Fig. 16.14** Radiographs following ORIF with prominent Kirschner wire (K-wire) not seated (my case)

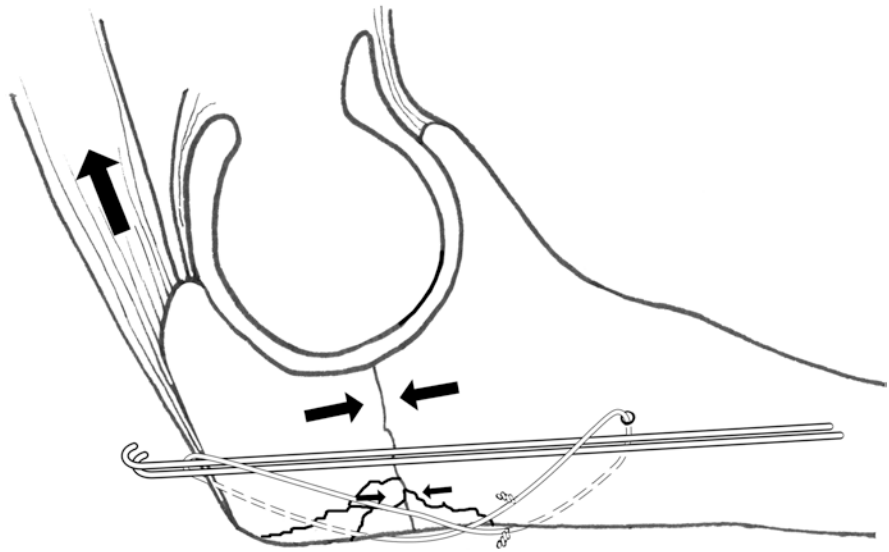


My preferred, default method is the use of the 6.5-mm screw (which will also be discussed in the next chapter), particularly in good-quality bone with minimal comminution. Comminution in itself does not preclude me from using the 6.5-mm screw, however, as the intramedullary screw affords excellent fixation and stability and has been used in fractures and osteotomies [11, 12].

### 16.1.2 K-Wire Positioning

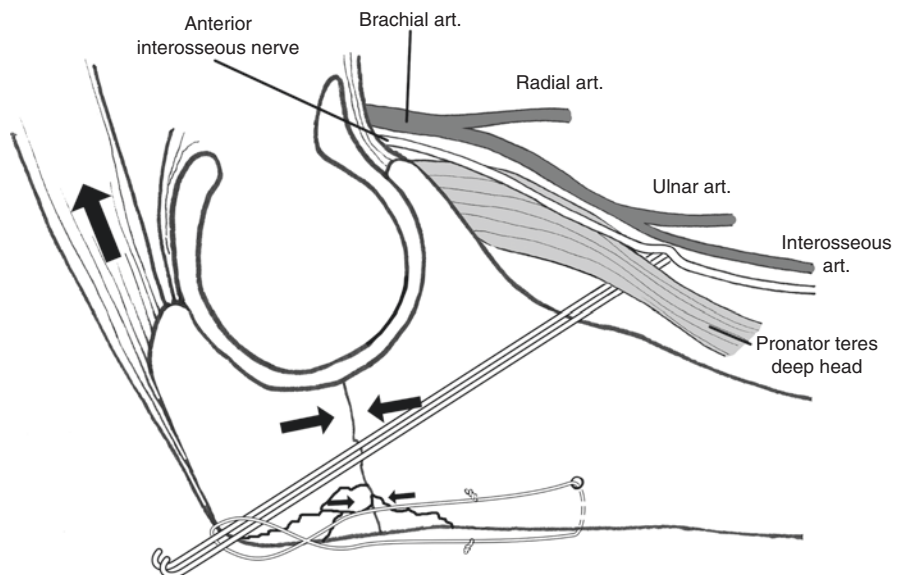
Before delving into the specifics of the fixation, the issues relative to K-wire positioning need to be clarified. I am a staunch advocate of utilizing longitudinal intramedullary K-wires, rather than parking the K-wires in the anterior cortex (Fig. 16.15).

**Fig. 16.15** My preferred positioning of K-wires longitudinally down the canal



I acknowledge some degree of theoretical biomechanical superiority with anterior placement, but I think the potential clinical disadvantages outweigh the biomechanical advantage [13].

First, there is concern about the structures anterior to the coronoid in the proximal ulnar shaft, which I believe are at risk, specifically the anterior interosseous nerve, which has been documented to have been injured consequent to a prominent K-wire (Fig. 16.16).



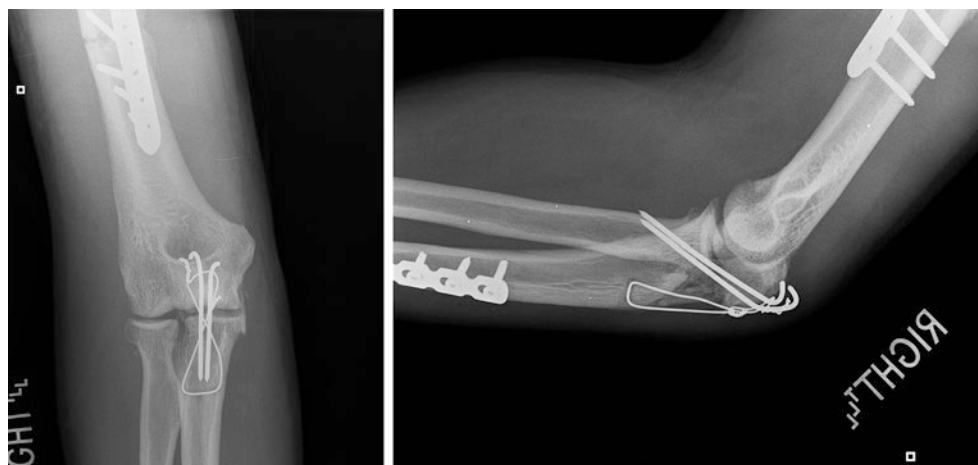
**Fig. 16.16** Potential anterior structure injury with prominent K-wires and insertion site close to comminution of dorsal cortex (The length of the K-wires may appear exaggerated in the drawing.)



Also, the proximity of the common interosseous ulnar artery to the K-wire tip needs to be appreciated [14], though I acknowledge that I have not seen specific reports of pseudoaneurysms or vascular compromise consequent to potential penetration. Another issue with anterior placement

is the thought process itself: the idea that a smooth device placed in a smooth hole captures or holds purchase to prevent backing out is not well founded. Also, there is the difficulty in establishing how far one can advance the K-wire after bending it over the tension band (Fig. 16.17).

**Fig. 16.17** Radiographs following transfer from referring hospital, showing right elbow with prominent K-wires anteriorly



If the oblique K-wire is backed out adequately and disengages the far cortex after drilling forward, there is potential for missing the anterior cortical hole when it is tamped into place or seated. Following the steps to be outlined, I believe that issues concerning the prominence of the longitudinal K-wires are obviated. I also have concerns over placing the bent K-wires at the apex of the olecranon, as this, in fact, becomes more prominent. Commonly, there are fracture fragments dorsally and significant potential for cut-out. Therefore, I avoid using anteriorly parked K-wires, except for fracture patterns that require it.

### 16.1.3 K-Wires Tension Band Construct, 6.5-mm Screw Construct

The next issue is the K-wires tension band construct and the 6.5-mm screw construct and the sequence of wire tightening. The tension band longitudinal K-wire construct should have the 18-gauge interosseous wire twist first, prior to seating the

K-wires, because of the tendency for the interosseous wire to break. If the longitudinal K-wires are already seated, it is much more difficult to retrieve and back out the K-wires in order to place a new interosseous wire.

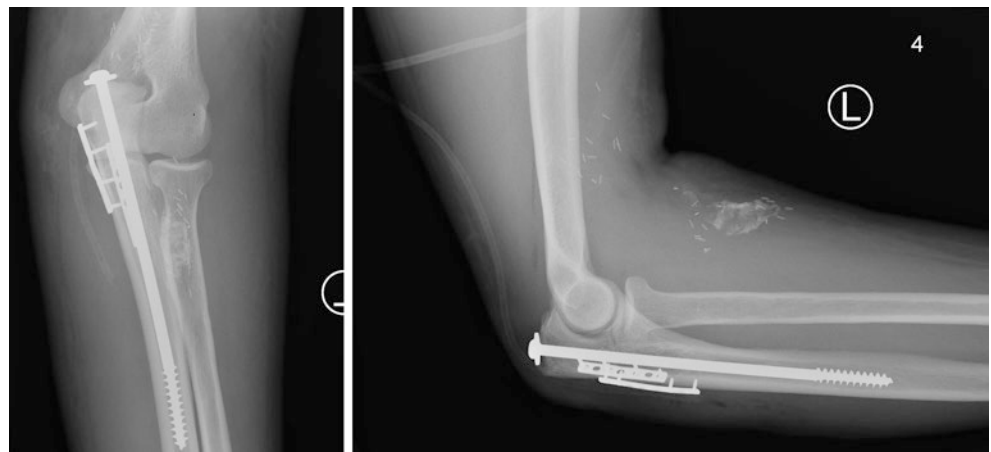
With the 6.5-mm screw, the opposite scenario exists. The 6.5-mm screw affords the most compression and stabilization, so it should be seated, followed by tension to the wire; if you tension the wire and advance the screw, you may loosen the tension on the interosseous wire.

The following initial steps are formatted for the tension band wire technique and the 6.5-mm screw technique. Occasionally, the canal size is such that an inadequate purchase exists for the 6.5-mm screw, in which case the 7.3-mm screw can be utilized. Another point is that the 6.5-mm screw is solid, versus either the 6.5-mm cannulated or 7.3-mm cannulated screw, and the bending of the screw is helpful in following the canal, versus any displacement; the cannulated screws tend to be stiffer and do not bend as much in situ (Figs. 16.18, 16.19, 16.20, and 16.21).

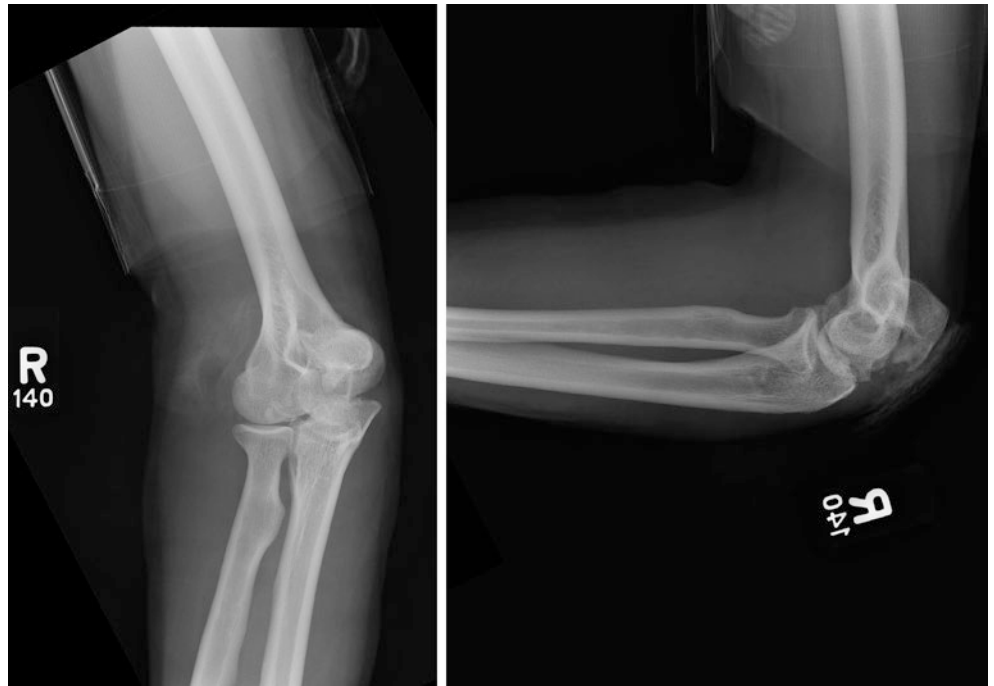
**Fig. 16.18** Injury radiographs of left olecranon fracture



**Fig. 16.19** Radiograph following ORIF, demonstrating a solid 6.5-mm screw following the curve of the ulna



**Fig. 16.20** Radiographs on presentation, showing an acute olecranon fracture (actually nonunion)



**Fig. 16.21** Radiographs following ORIF. Note that the cannulated 6.5-mm screw is not contouring to the ulna but is maintaining a straight course





The solid screw that bends and follows the canal affords the opportunity to be center/center on the olecranon process and avoids the need to favor a radial starting point to get down the canal. This avoids lateral wall cut-out.

## 16.2 Operative Technique

### 16.2.1 Patient Positioning

The patient is positioned supine. I generally approach the olecranon from the lateral side of the elbow with the arm

flexed, resting on a gown bump, and the elbow flexed to 90°. Some portions of procedures may be performed with the arm across the chest on a bump. (Patient prep and drape are demonstrated in Chap. 15, including distal placement of the hand table and a sterile tourniquet).

### 16.2.2 General Approach

A posterolateral approach is used, not directly over the olecranon (Figs. 16.22 and 16.23).

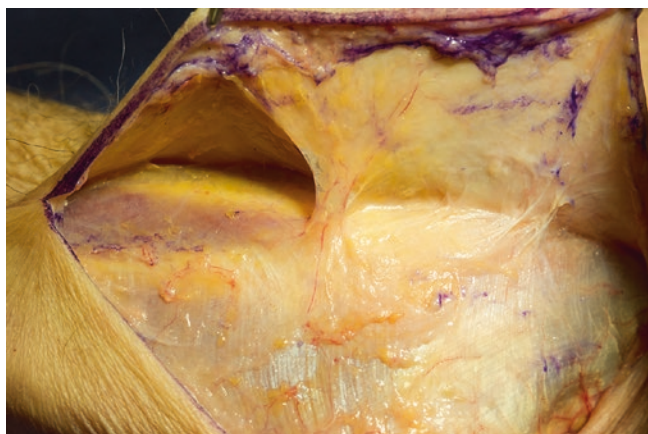


**Fig. 16.22** Posterolateral skin incision for approach to left olecranon



**Fig. 16.23** Posterior view of incision, demonstrating that the incision is not directly posterior

Elevate a skin flap over the proximal forearm fascia to the level of the lateral epicondyle (Fig. 16.24).



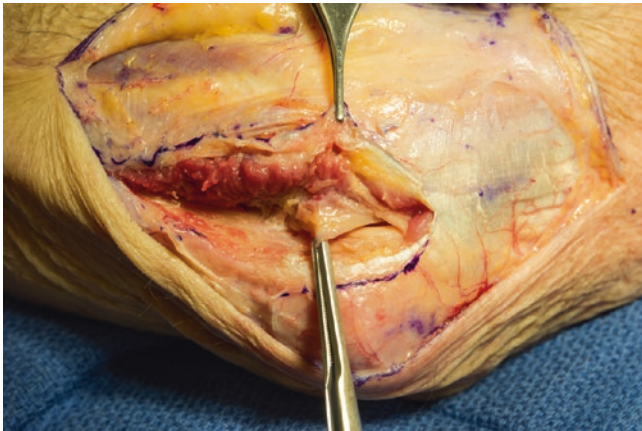
**Fig. 16.24** Lateral skin flap elevated with recurrent radial artery perforators coursing into the flap

Elevate the anconeus from the lateral olecranon and proximal ulna shaft—but not too proximal, so as not to denervate the anconeus by injuring the radial nerve innervation to the anconeus, which is a continuation of the innervation to the medial head of the triceps (Fig. 16.25).

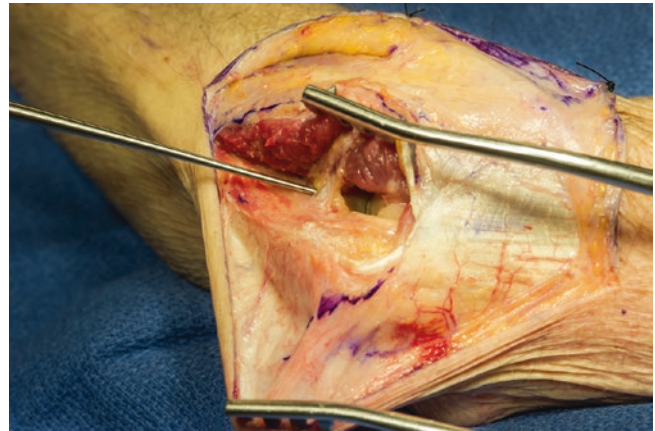


**Fig. 16.25** Deeper fascial incision

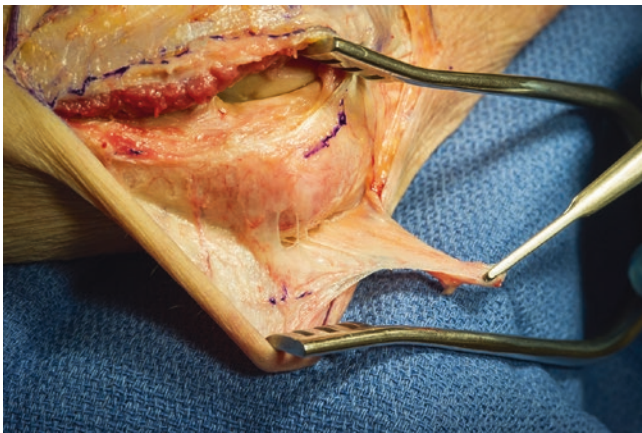
Elevate the anconeus distal, but do not disrupt the annular ligament insertion into the crista supinatoris (Figs. 16.26, 16.27, and 16.28).



**Fig. 16.26** Anconeus elevated and posterolateral synovectomy to allow joint visualization



**Fig. 16.27** Annular ligament insertion into the crista supinatoris preserved



**Fig. 16.28** Olecranon bursa excision

Utilize medial elevation and dissection to visualize medial fragments if present. Unless dictated by medial fixation requirements or debridement for open fractures, the ulnar nerve is not visualized.

Elevate marginal impacted fragments, usually just proximal to the bare area, and raft with K-wires. Use smooth K-wires, because they will be incarcerated (Figs. 16.29, 16.30, 16.31, and 16.32).

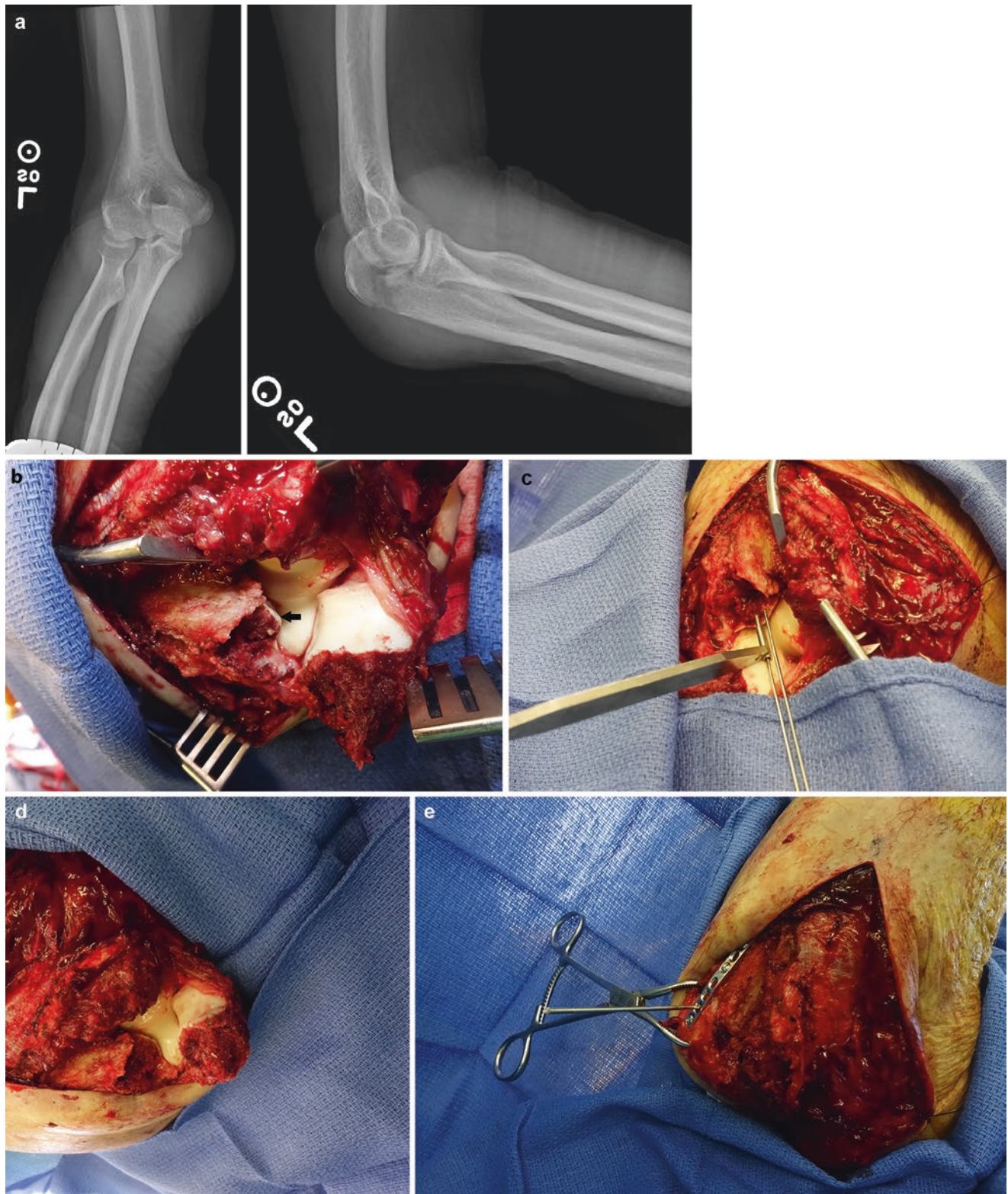
**Fig. 16.29** Injury radiographs of right olecranon fracture with articular impaction



**Fig. 16.30** Radiographs following ORIF, including rafting with K-wires







**Fig. 16.31** (a) Injury radiographs on presentation, showing left olecranon fracture with articular comminution and impaction. (b) Impacted olecranon process fragment (*arrow*). (c) Fragment elevated and rafted

with K-wires inserted, then backed out a couple of millimeters, cut, and tamped flush or recessed. (d) Reduction and fixation of fragment. (e) Fixation prior to intramedullary screw insertion

**Fig. 16.32** Radiographs following ORIF, including rafting K- wires. Note screw also assisting rafting or supporting the joint elevation

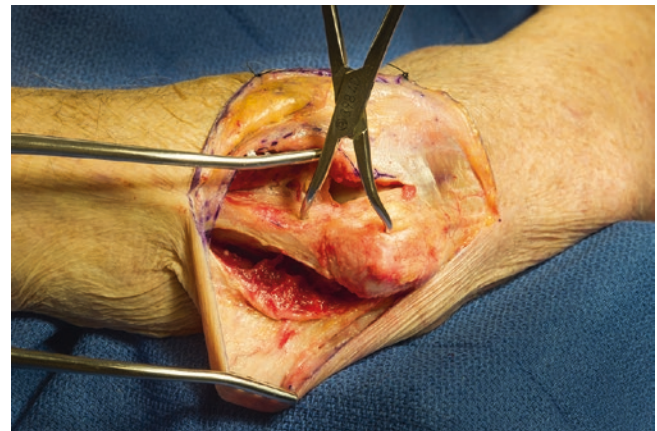


When rafting, drill the K- wire in, then back out slightly, then cut and tamp in. Consider pre-drilling small fragments with a 1.1-mm or 1.5-mm drill bit; then insert the K-wire. If a threaded K-wire is felt to be needed, then use two K-wires. Use a smooth K-wire first, then add the threaded one. If you

start with the threaded wire, the fragment may spin or displace. If necessary, use a round cutting burr, 2 mm or 3 mm in diameter, to recess the prominent cut end of the threaded K-wire. Perform provisional reduction with either a tenaculum or mini-fragment plates (Figs. 16.33 and 16.34).



**Fig. 16.33** Unicortical hole drilled for purchase of a tenaculum so it doesn't slip



**Fig. 16.34** Reduction performed and held with a tenaculum

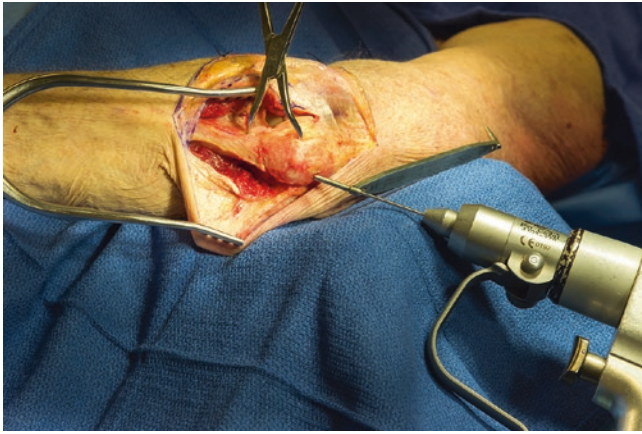
For longitudinal wire insertion, the arm may be placed across the chest on the gown bump *if* it is not possible to position the arm on the bump on the hand table.



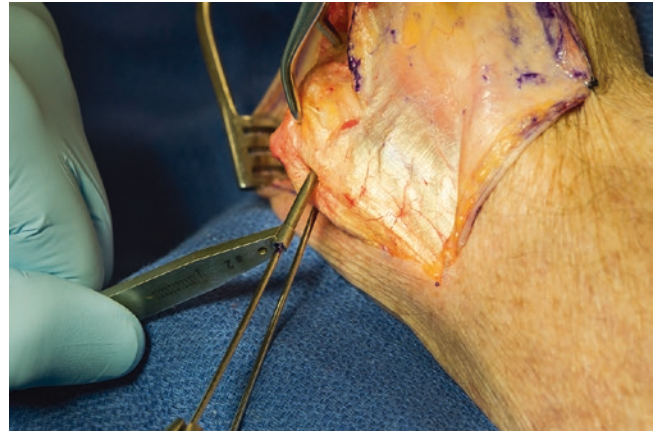
### 16.2.3 K-Wire Tension Band Fixation

With the provisional fixation completed and the arm resting with the elbow on a gown bump and the elbow flexed, drill in

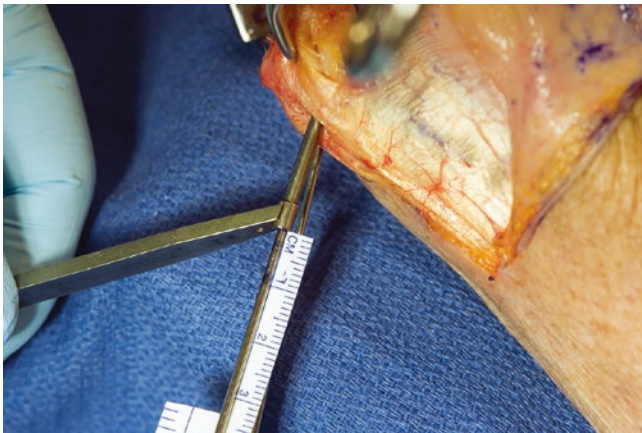
two K-wires, 0.0625 in. intramedullary. Drill in, then back out approximately 1 cm to allow subsequent advancement. The wires will converge slightly (Figs. 16.35, 16.36, 16.37, 16.38, and 16.39).



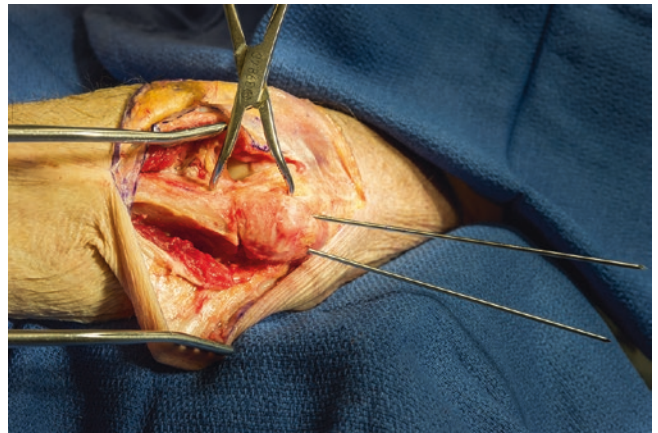
**Fig. 16.35** First 0.0625-in. K-wire inserted using a soft tissue protector. The K-wire is advanced down the canal and not into the anterior cortex



**Fig. 16.36** Second K-wire inserted in converging fashion



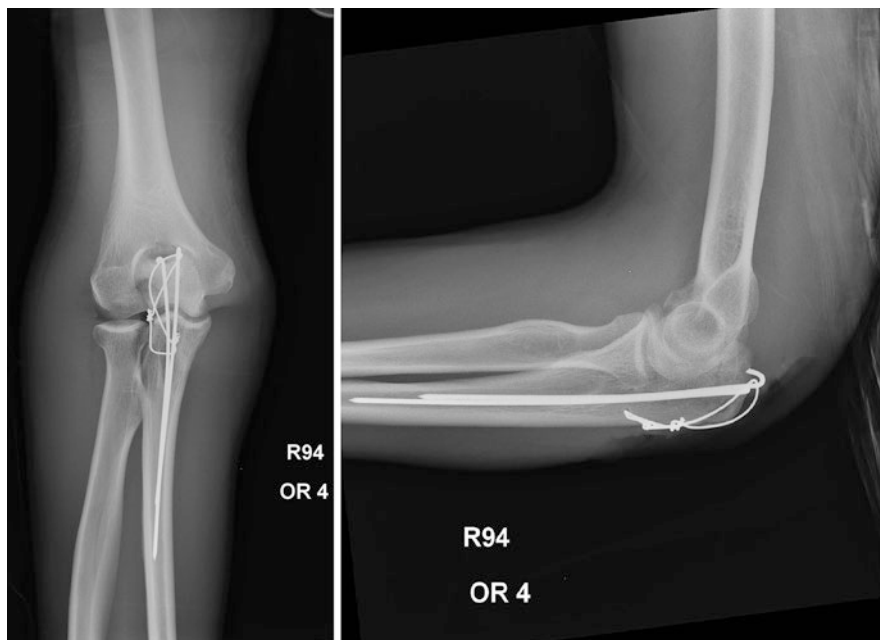
**Fig. 16.37** The K-wires are inserted, then backed out about 1 cm



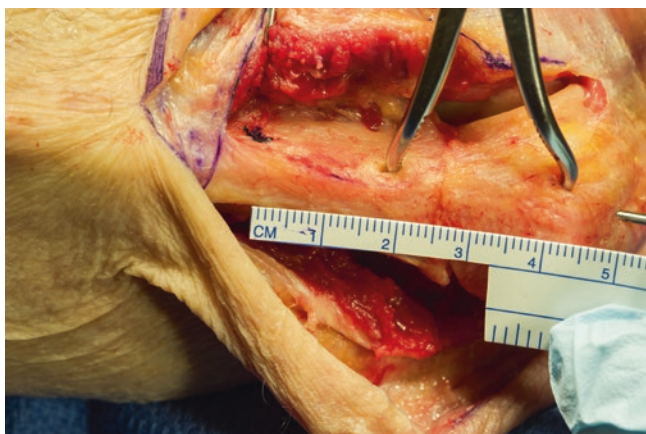
**Fig. 16.38** Both K-wires inserted; note the convergence of the wires



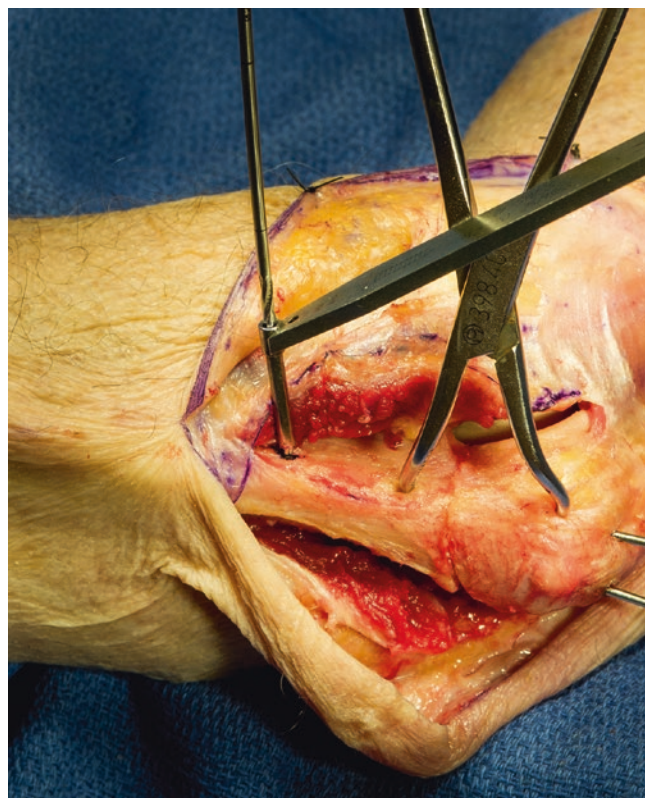
**Fig. 16.39** Intraoperative radiographs demonstrating converging, seated longitudinal K-wires



Drill a transverse hole with either a 2.0-mm or 2.5-mm drill bit, bicortically 2.5 cm distal from the fracture (Figs. 16.40 and 16.41).

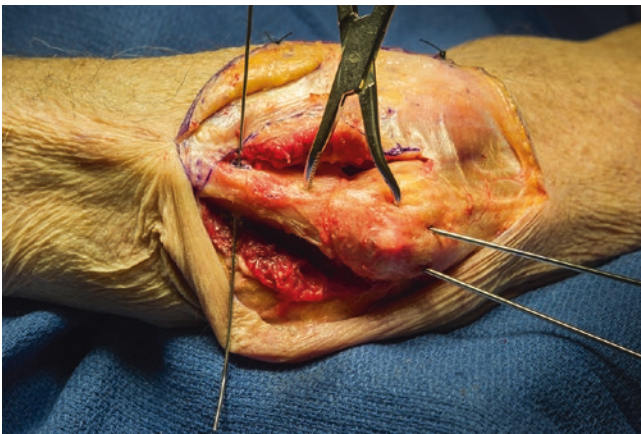


**Fig. 16.40** Transverse hole drilled 2.5 cm distal to the fracture (or osteotomy)



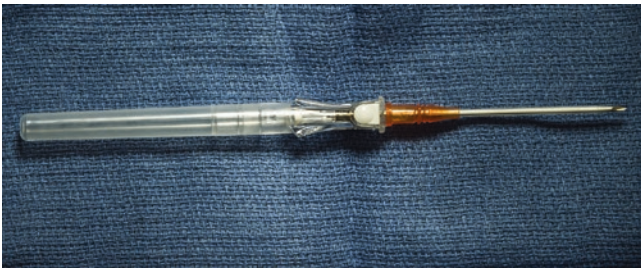
**Fig. 16.41** Drilling hole with either a 2.0-mm or 2.5-mm drill bit. The hole favors a slight dorsal position, which will be more critical if using the longitudinal screw

Place an 18-gauge wire through the hole (Fig. 16.42).



**Fig. 16.42** 18-gauge wire inserted through hole

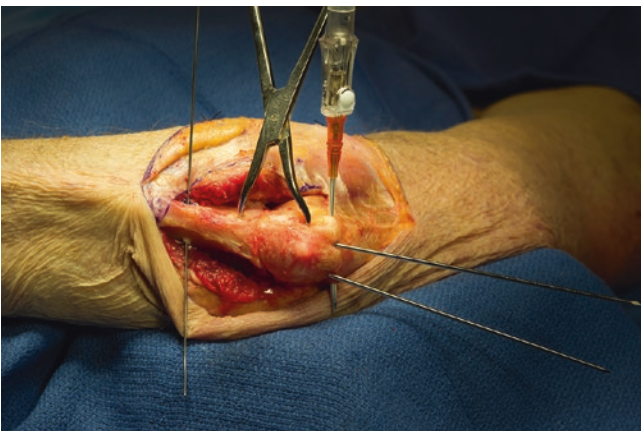
Put a 14-gauge angiocatheter through the triceps at the bone/tendon/K-wire juncture; note the slight curve of the angiocath (Figs. 16.43, 16.44, 16.45, and 16.46).



**Fig. 16.43** 14-gauge angiocath with very slight curve placed



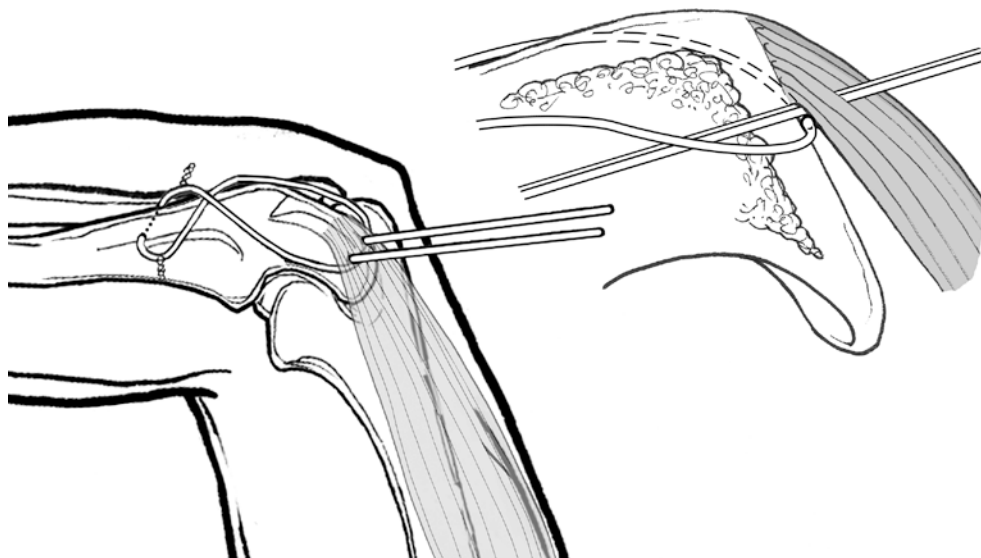
**Fig. 16.44** Angiocath inserted through triceps at the pin/bone/tendon juncture



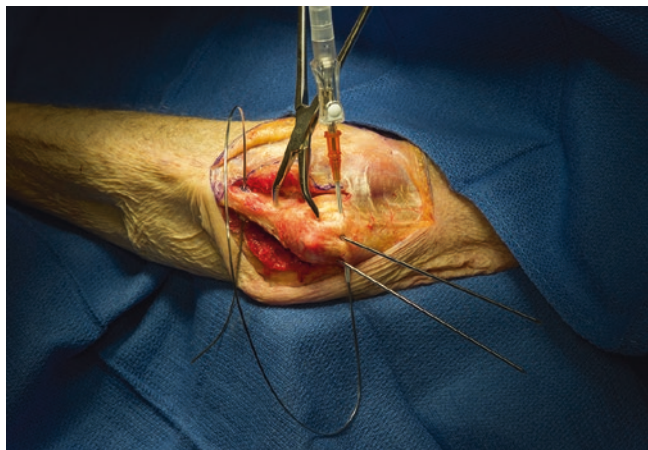
**Fig. 16.45** Angiocath advanced through the triceps



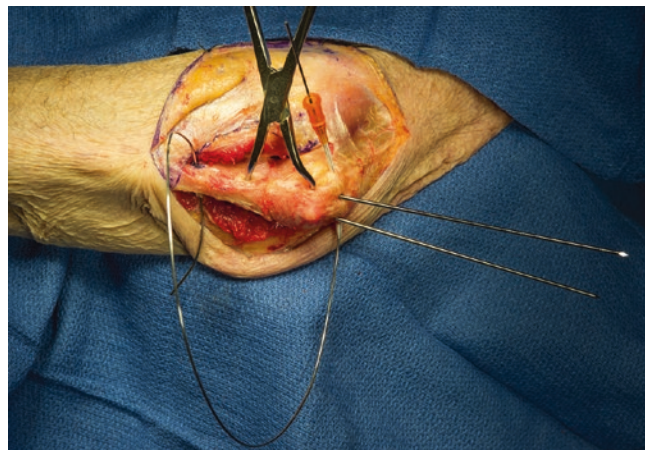
**Fig. 16.46** Diagrammatic representation of 18-gauge wire position



Pass one end of the 18-gauge wire through the 14-gauge angiocath to construct a figure-eight design (Figs. 16.47 and 16.48).

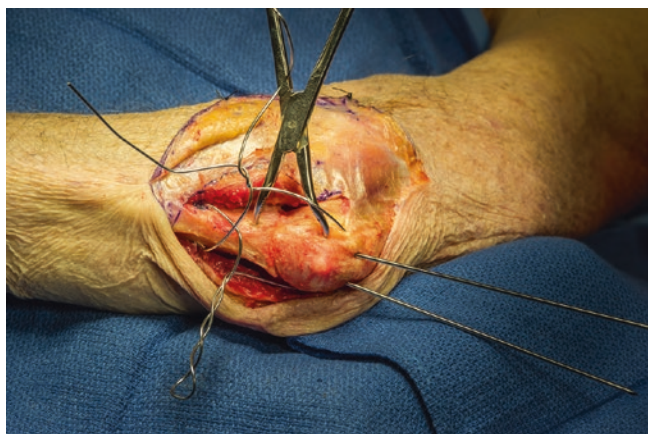


**Fig. 16.47** Beginning of figure-eight tension band wire construct. The proximal end of the wire is crossed over and fed into the angiocath



**Fig. 16.48** Wire advanced through the angiocath

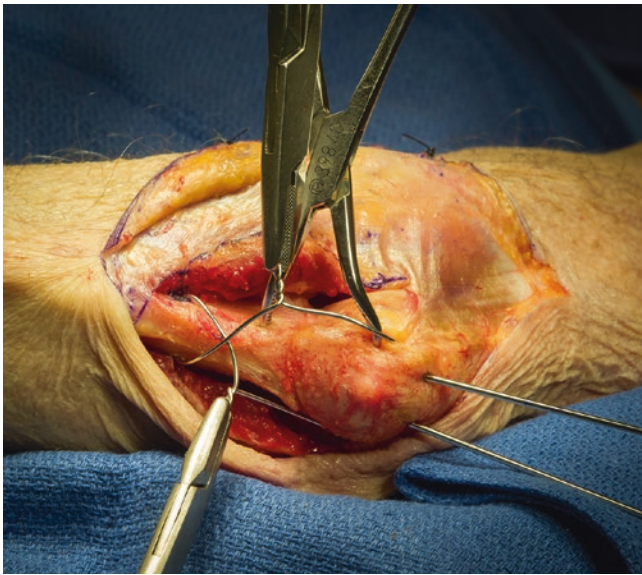
Make double twists in the 18-gauge wire (Fig. 16.49).



**Fig. 16.49** Preliminary twisting of wires; note the symmetrical twists, and the knots to be slightly distal to the fracture



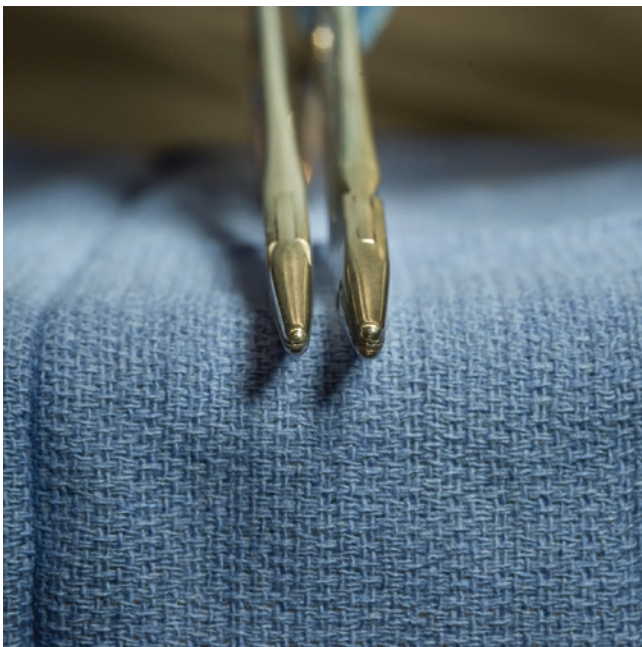
Keep twisting the device in the crotch of wires to make uniform twists (Fig. 16.50).



**Fig. 16.50** When twisting the wires, be sure to stay in the crotch of the limbs so as to ensure helical twists. Do not make the final tensioning twists yet

Place the twists not at the fracture site, but between the fracture and the transverse hole in the ulna. ***Do not final twist the tension band wires.*** Bend the 0.0625-in. K-wires and cut the ends obliquely to improve seating into the tri-

ceps and olecranon process, but don't turn or tamp in the ends yet. Use needle drivers with rounded tips, not wire twisters (Figs. 16.51, 16.52, 16.53, 16.54, 16.55, 16.56, and 16.57).



**Fig. 16.51** Needle driver selection for turning down the K-wires. Note the rounded contour; do not use wire twists because you can't get the nice, curved bend as well

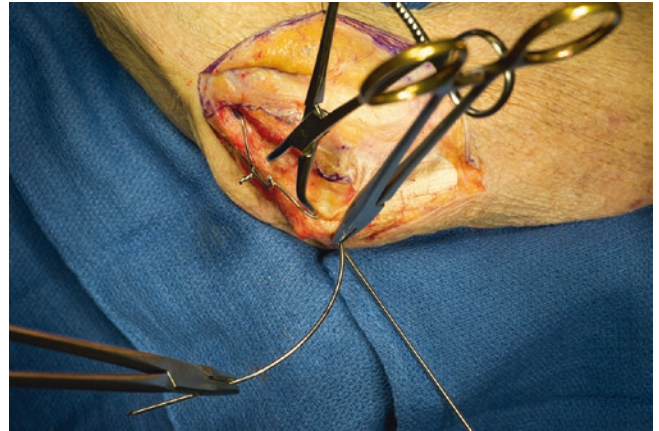


**Fig. 16.52** Top view

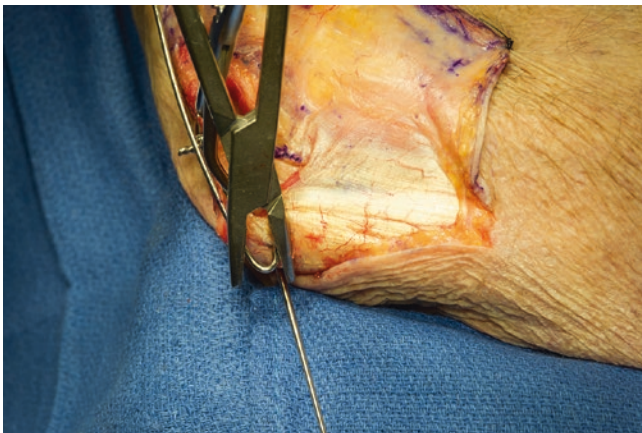




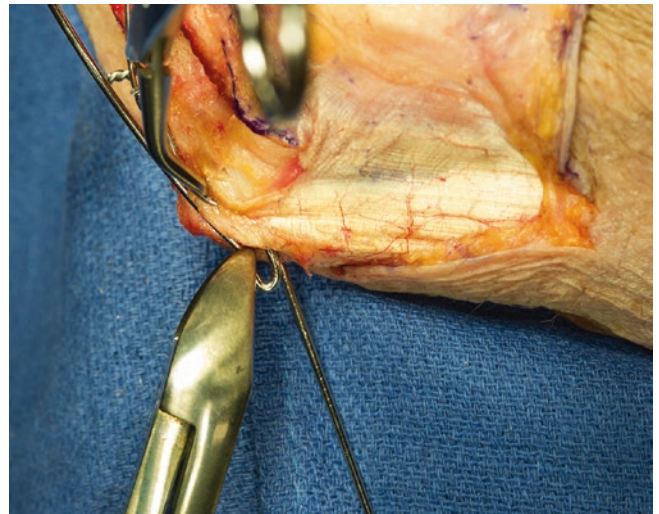
**Fig. 16.53** Side view



**Fig. 16.54** Needle driver grasping the K-wire, with the opposite hand turning down the long end



**Fig. 16.55** Crimp down the K-wire



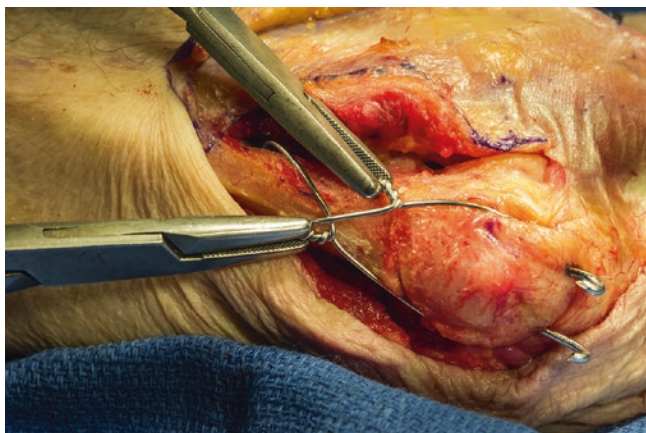
**Fig. 16.56** Cut the K-wire on the bias (obliquely), leaving 3 or 4 mm of the wire to be turned and tamped in place. (If you don't know what "cutting on the bias" means, ask your mother)



**Fig. 16.57** Wire cut and ready to be turned

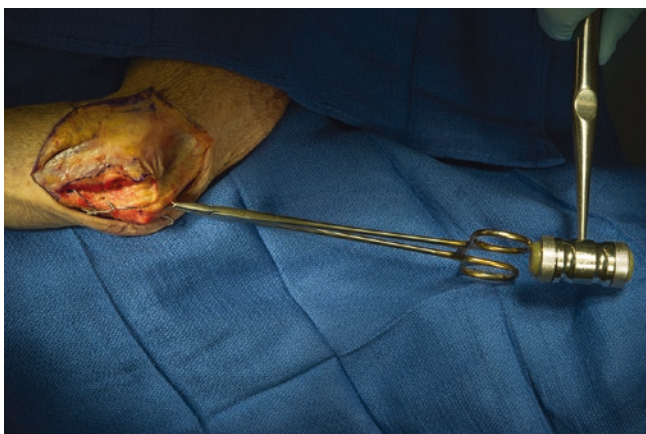


Perform the final twists to the 18-gauge wire. You will need about four twists to manipulate the wire: Twist and turn down at the same time to maintain compression, and turn the twisted ends away from the crest of the ulna (Fig. 16.58).



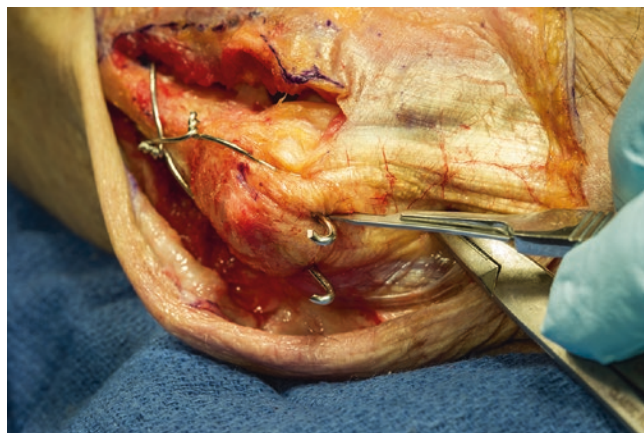
**Fig. 16.58** Perform the final twists and turning down of the 18-gauge wire all in one smooth motion, to maintain the tension generated by the twists. If you twist and then push down, you lose any tension or compression

Turn the ends of the K-wires 180° using heavy needle holders, and tamp the wires into place. Use a tamp for the



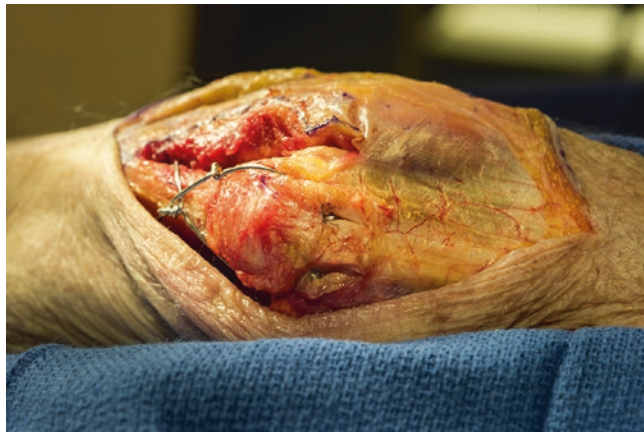
**Fig. 16.60** Using a needle holder, turn the K-wire, then tamp it into the triceps slit. This is why you drilled the K-wires in and then backed out, so they have a path to advance, as long as you didn't hit the cortex

Make proximal slits in the triceps from the K-wires proximally (Fig. 16.59).



**Fig. 16.59** Make slits in the triceps proximally

final seating. The wires should glide into previously made slits in the triceps (Figs. 16.60 and 16.61).



**Fig. 16.61** Seated K-wires. You can see why the tension band wire is tensioned and then the K-wires are advanced, because if you break the wire during the twisting, it can be a pain to retrieve and back out the K-wires. Believe me



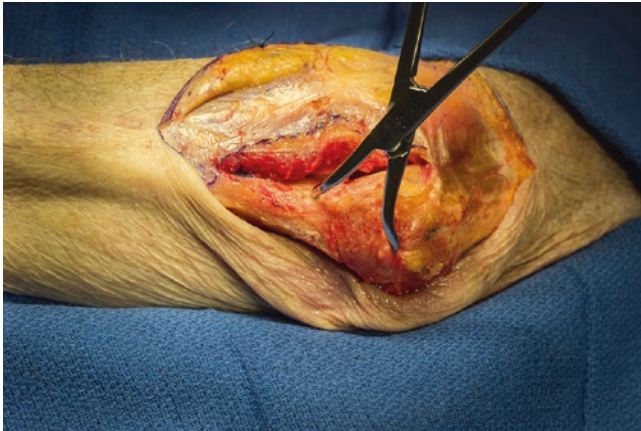
You need to use this sequence of K-wire twists first, then seating. Otherwise, if the tension band wire breaks and you have seated the K-wires, it can be very difficult to retrieve the K-wires to start all over again. Having the K-wires prominent makes replacement of the tension band wire much easier.

With the 6.5-mm screw technique, the sequence of screw seating and wire twisting is opposite. Also realize that bio-

mechanical studies show the “tension band” principle does not result in compression on the articular side [12].

#### 16.2.4 Intramedullary Screw: 6.5-mm/7.3-mm

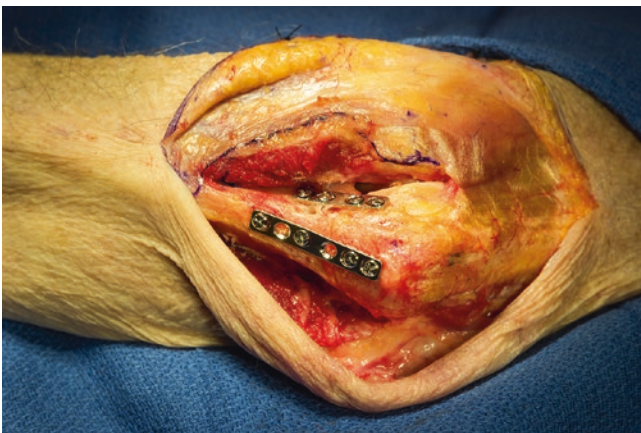
Use initial approach, with provisional reduction (Figs. 16.62, 16.63, and 16.64).



**Fig. 16.62** Reduction performed in preparation for provisional mini-fragment plate fixation



**Fig. 16.63** Two 2.0-mm mini-fragment plates placed; the dorsal plate acts as a “tension band” and the radial plate is positioned to resist the torquing during insertion of the 6.5-mm screw



**Fig. 16.64** Elbow positioned for triceps split

Make a generous slit in the triceps from the dorsal surface of the olecranon process proximally, at least 2.5 cm. There is a tendency for the incision in the triceps to be made too distally (Fig. 16.65).



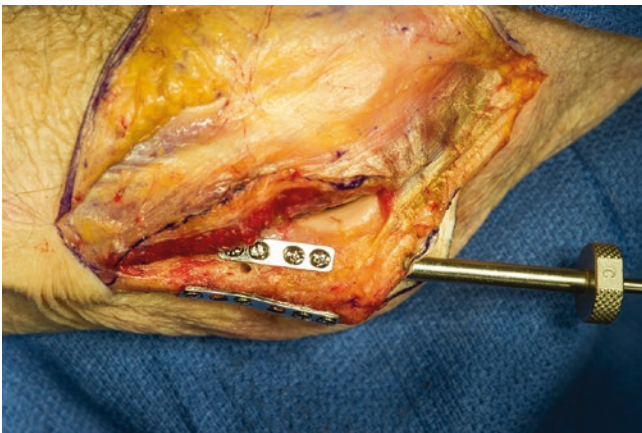
**Fig. 16.65** Generous incision outlined on the triceps, to allow drilling in a center/center (not radial) position

Place a 2/3 prong sharp self-retractor in the triceps opening (Fig. 16.66).

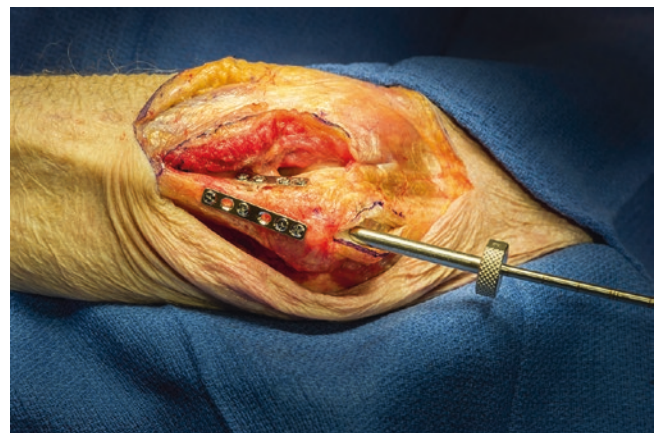


**Fig. 16.66** Incision in triceps with 2/3 prong self retractor inserted

Pre-drill with a long 3.2-mm drill bit (Figs. 16.67 and 16.68).



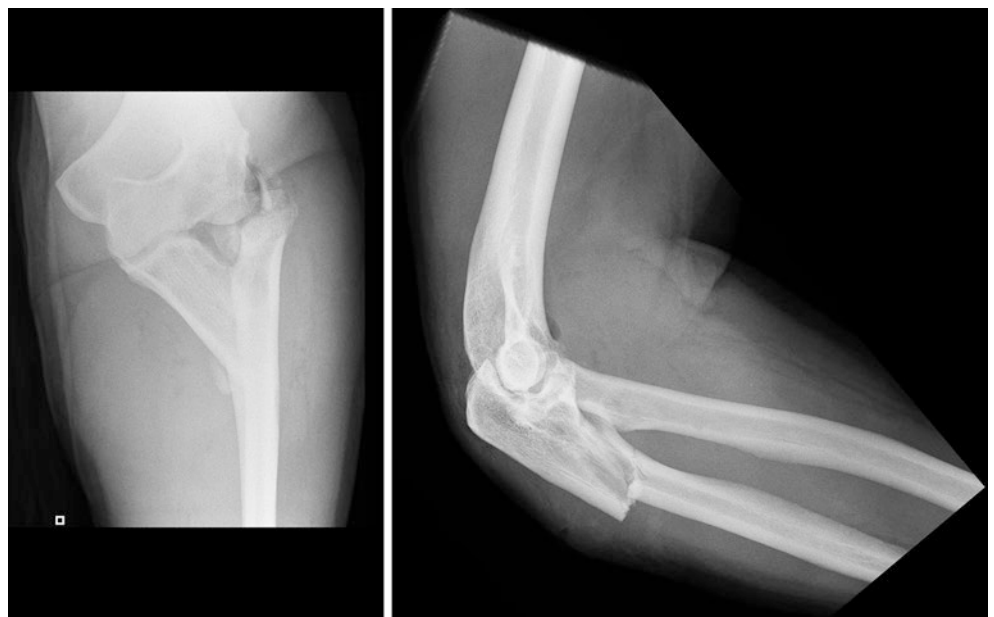
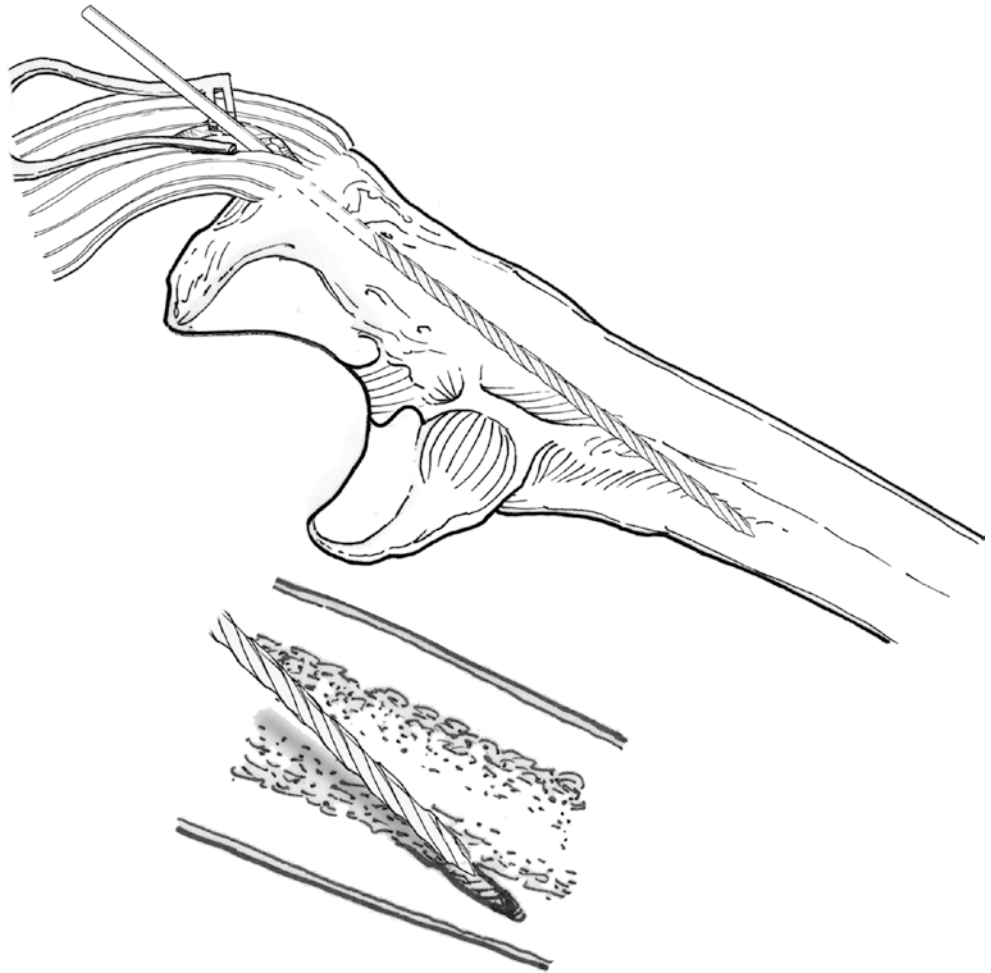
**Fig. 16.67** Starting position on lateral view midway between the dorsal cortex and joint. I routinely use a soft tissue protector during this phase of the drilling. Also, the arm may be positioned across the chest at this point of the operation



**Fig. 16.68** Center starting point medially and laterally, with a 3.2-mm drill bit used for initial drilling

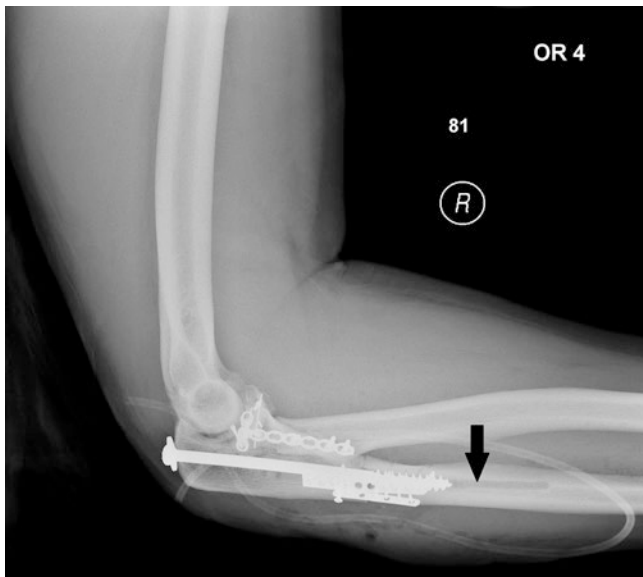
Do not force or engage the endosteal surface, so not to create a shoulder, and make a blind path (Figs. 16.69, 16.70, and 16.71).

**Fig. 16.69** Traversing down the canal is critical, to avoid engaging the endosteal surface and creating a shoulder or blind passage



**Fig. 16.70** Radiographs of a left elbow transolecranon fracture dislocation, to demonstrate endosteal drilling

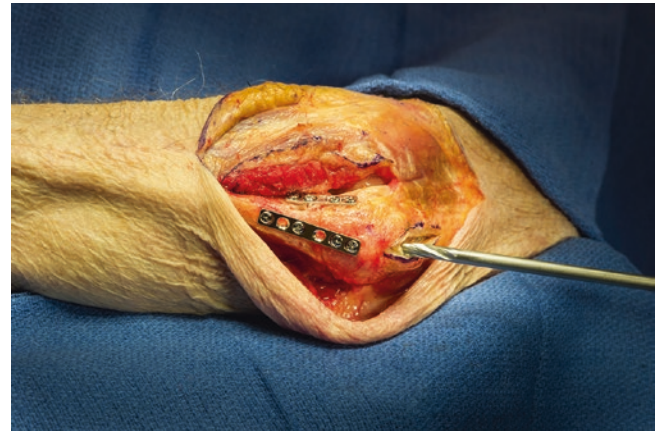




**Fig. 16.71** Radiograph of final fixation with endosteal drilling (*arrow*) and potential for cutting out of the screw if a longer screw had been needed

Tap, beginning with power, and when the purchase starts to slow down the drill, remove the drill. Put the T-handle device on the tap and complete the tapping until you almost can't advance any more. Hold the forearm with your free

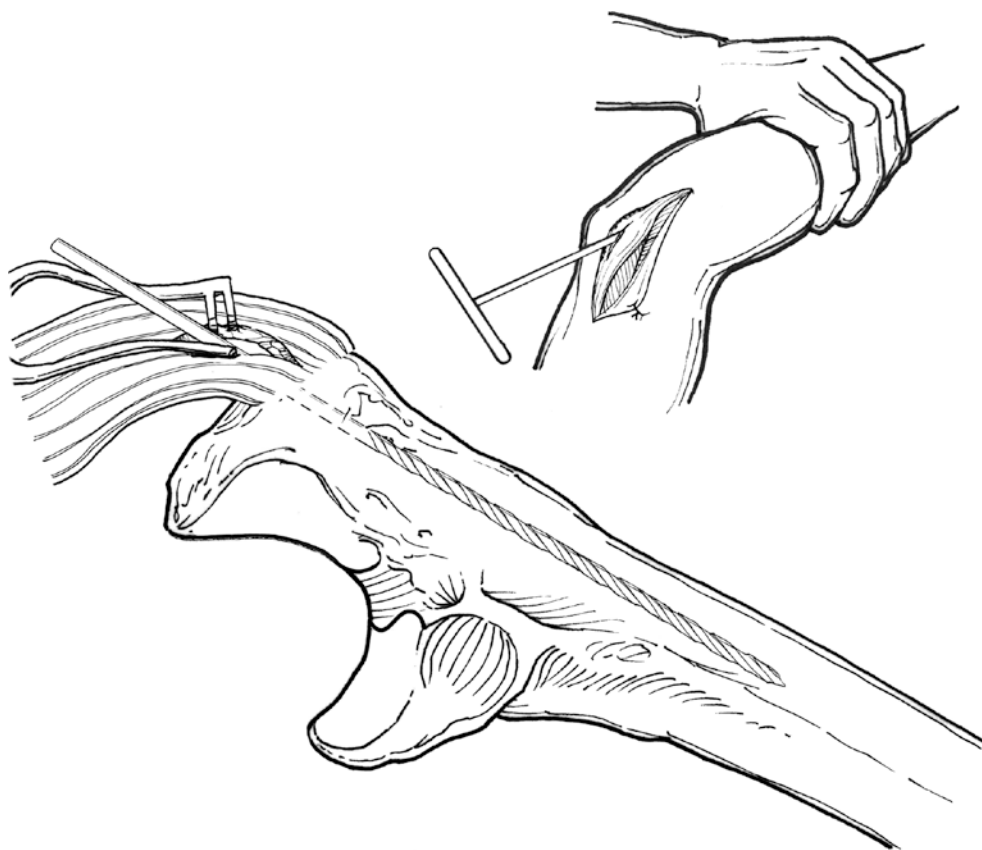
The starting point is center/center; I do not favor a lateral position, though some surgeons like to start lateral because of the bow of the ulna. I am concerned about cutting out the lateral cortex. Over-drilling the proximal fragment also tends to prevent any lateralizing of the proximal fragment. The screw will bend to follow the curve of the canal. Over-drill the proximal ulna to the level of the coronoid with 4.5-mm drill bit (Fig. 16.72).



**Fig. 16.72** Over-drilling the proximal ulna with a 4.5-mm drill bit to the level of the coronoid. A soft tissue protector should be used clinically, though it is not shown here

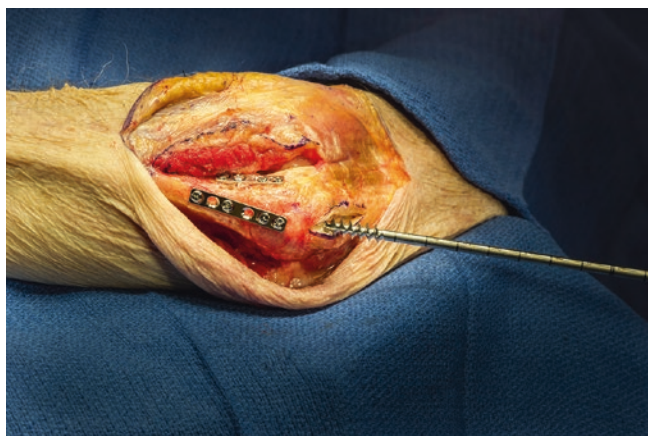
hand, or hold the ulna shaft with a lobster-claw clamp to prevent torquing the arm when tapping. The length of the screw will be determined using the tap, not a depth gauge (Fig. 16.73).

**Fig. 16.73** Proper orientation of drill bit down the canal, holding the forearm with the free hand during tapping



The tap should go in until you cannot advance any farther; then subtract 5 mm to allow some compression. For exam-

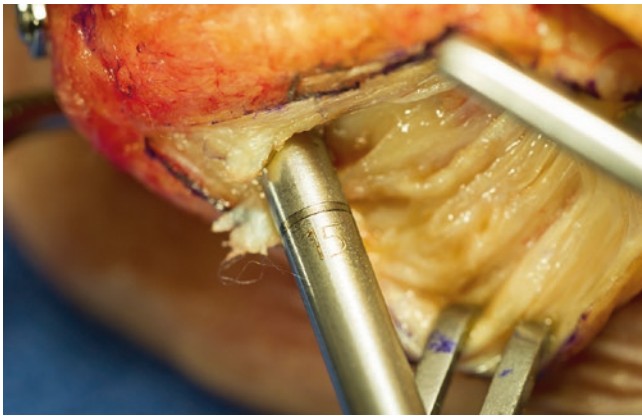
ple, if you tap to 135 mm, use a 130-mm screw (Figs. 16.74, 16.75, 16.76, and 16.77).



**Fig. 16.74** Tapping with 6.5-mm tap (Use a soft tissue protector)



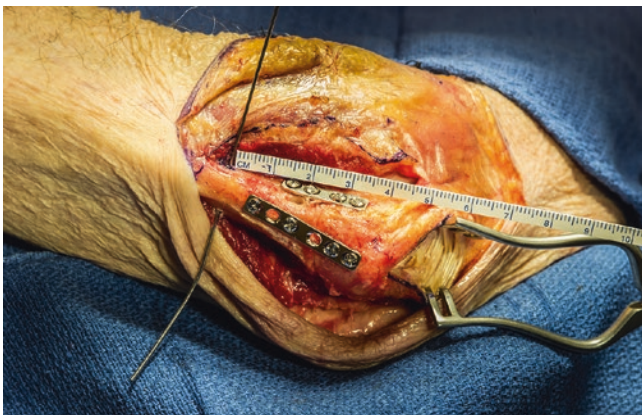
**Fig. 16.75** Hold the proximal fragment to limit motion during tapping



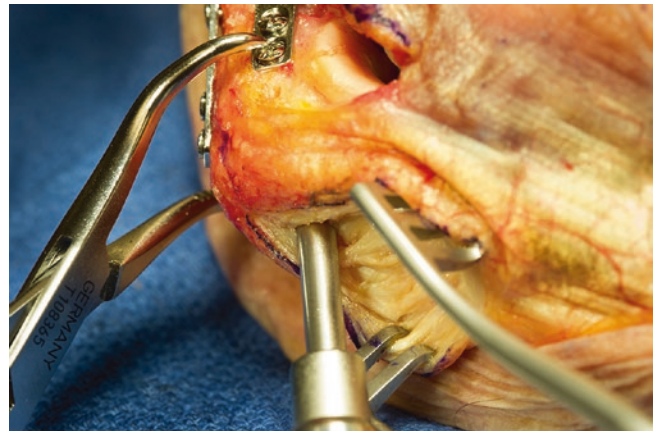
**Fig. 16.76** Tapping must advance until you can't advance any more. (During this process, you may hear some disconcerting "creaks.") You also need to tap past the projected screw length to get some compression

If you are using a tension band wire, drill the transverse hole with either a 2.0-mm or 2.5-mm drill bit, bicortically 2.5 cm distal from the fracture, favoring towards the dorsal cortex to avoid notching the 18-gauge wire with the screw, when the screw is inserted.

Place the 18-gauge wire through the transverse hole, but don't pull the wire through. To have equal lengths of wire on either side, you will pull the wire through after the screw is partially inserted (Fig. 16.78).



**Fig. 16.78** Once the tap is removed, after the screw length has been established with the tap (not a depth gauge), insert the 18-gauge wire through the transverse hole but do not pull it all the way through yet



**Fig. 16.77** Note that the tap is buried past the 150-mm mark

Use a 32 mm–thread screw with a washer and advance until about 1.5 cm from full seating (Fig. 16.79).

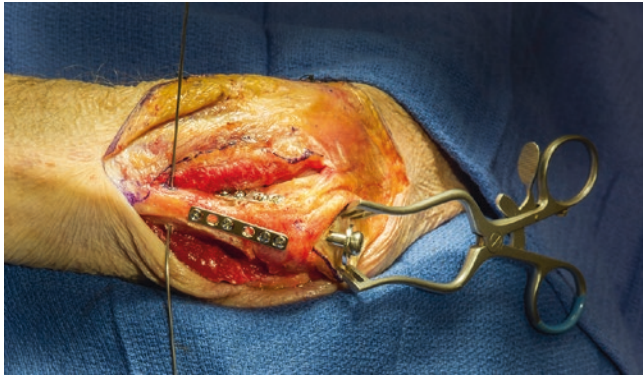


**Fig. 16.79** 6.5-mm screw (150-mm length, 32-mm threads) with a washer

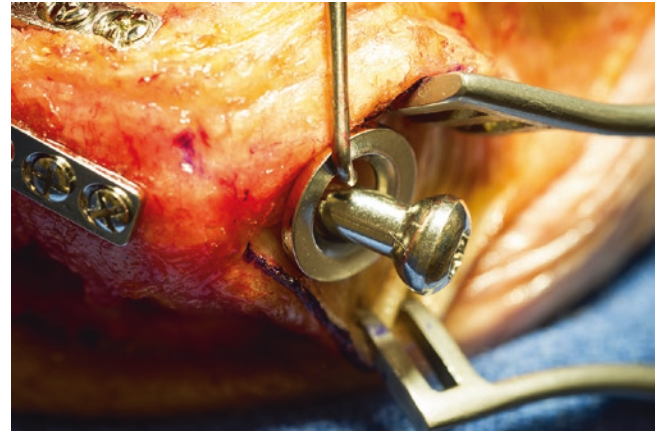


Insert the 6.5-mm screw—or 7.3-mm if purchase was poor with the 6.5-mm tap, in which case you will need to place the 7.3-mm guide wire, over-drill proximally, and re-tap. Pull the 18-gauge wire through and make a figure eight with a double

twist, but don't tighten all the way. Hook the tension band wire around the shaft of the screw, under the washer, not through the triceps as in the K-wire method (Figs. 16.80 and 16.81).



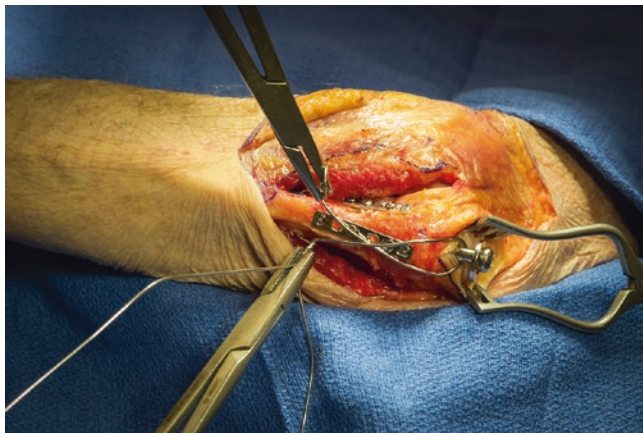
**Fig. 16.80** Now pull the 18-gauge wire through, because the screw may hit and notch the wire during the insertion



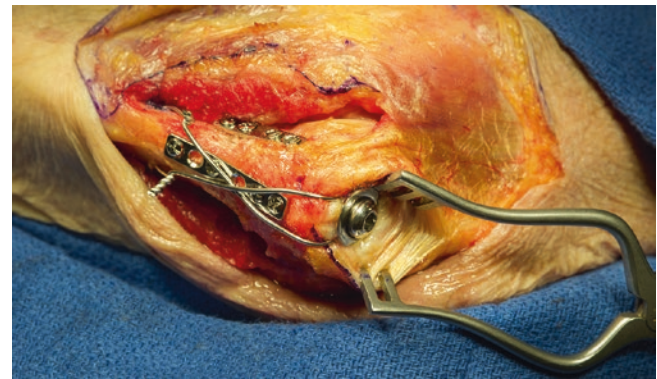
**Fig. 16.81** Leave about 1 to 1.5 cm of the screw out, to loop the 18-gauge wire around the screw, not through the triceps

Twist the wire to give some tension but do not final twist (Fig. 16.82).

Now seat the screw, holding the forearm to prevent torquing (Fig. 16.83).



**Fig. 16.82** Wire looped around the screw. The combination of plates and tension band wire is not necessarily used or needed, but is shown for demonstration. Note the needle drivers in the crotch of the wires



**Fig. 16.83** Wires are twisted, but the final twist is not made until the screw is seated. If you final-twist the wires too early, you may lose some tension when the screw is seated

Tighten the 18-gauge wire with the final twists and turn the wire down, away from the crest of the ulna (Figs. 16.84, 16.85, 16.86, 16.87, and 16.88).

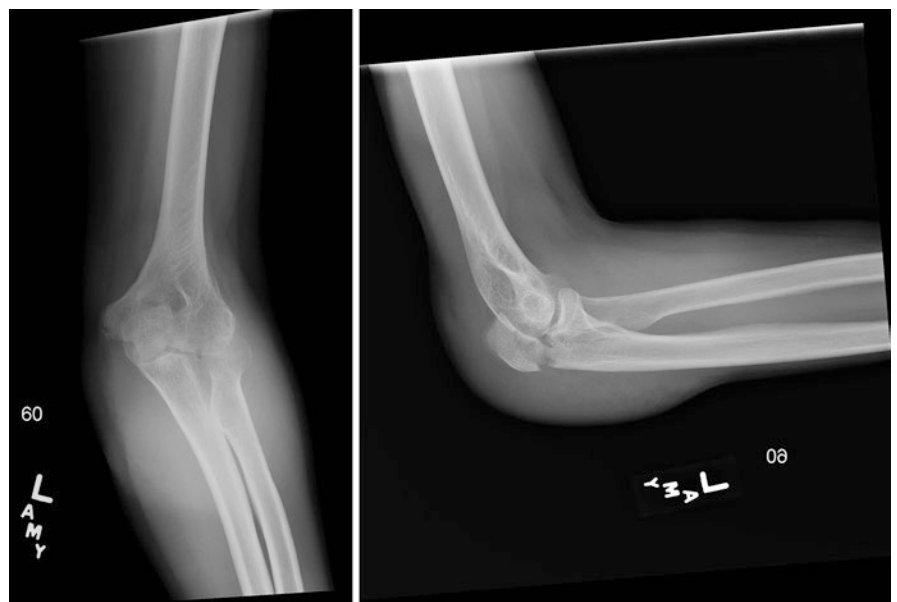
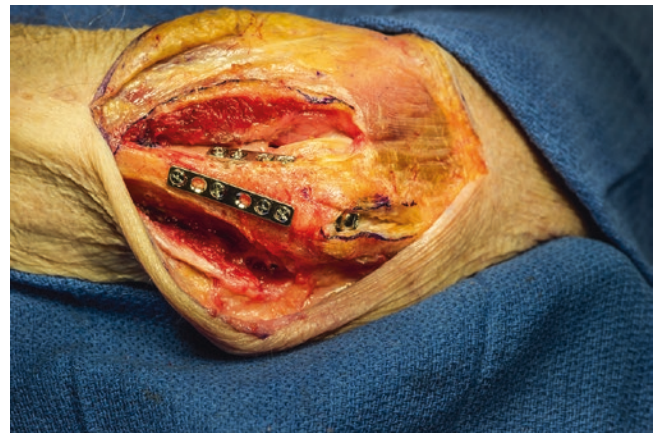


**Fig. 16.84** Final construct



**Fig. 16.85** Final construct, lateral view

**Fig. 16.86** Final construct without tension band wire. With good reduction and interdigitation, neither the plates nor wires may be required



**Fig. 16.87** Radiographs of left elbow with olecranon fracture with impaction of the joint



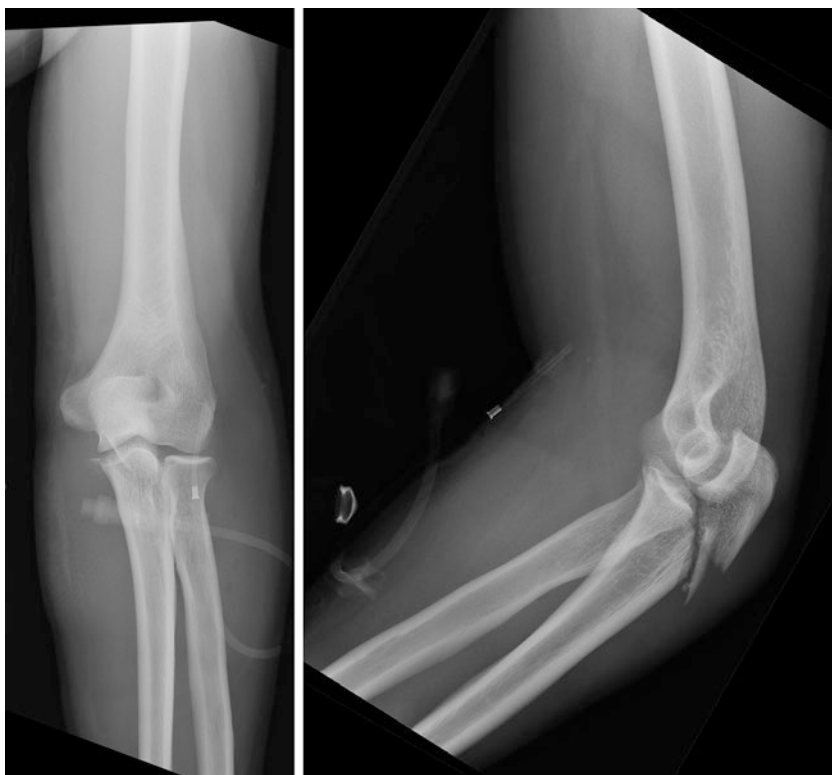
**Fig. 16.88** Radiographs following ORIF with rafting K-wires, plates, and longitudinal screw but not tension band wire. (Note the cast for a distal radius fracture, at first follow-up 10 months postoperatively)



If you had completely tightened the wire, then the screw, the wire would become loose.

If the 6.5-mm screw doesn't gain purchase, step up to a 7.3-mm (or 8.0-mm) screw. If still not attaining adequate

purchase, change to the K-wire technique (Figs. 16.89, 16.90, 16.91, 16.92, 16.93, and 16.94).

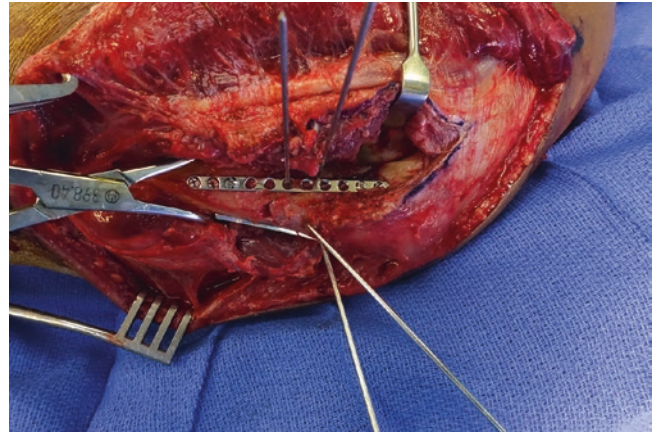


**Fig. 16.89** Radiographs of left olecranon process fracture

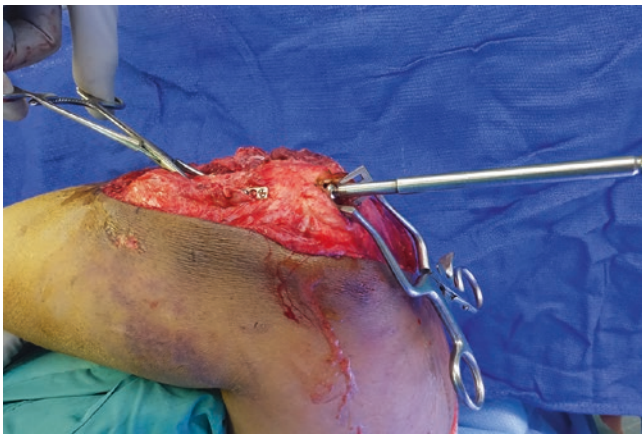




**Fig. 16.90** Skin incision outlined for posterolateral approach



**Fig. 16.91** Approach completed with lateral capsulectomy for joint visualization and provisional K-wire, followed by unicortical mini-fragment plates



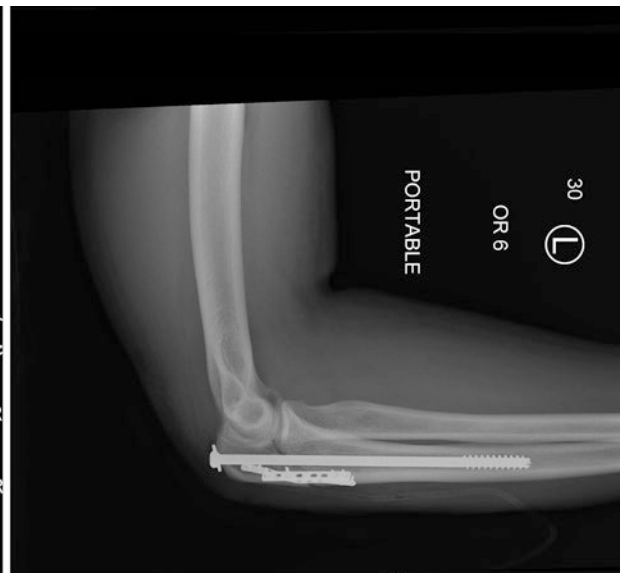
**Fig. 16.92** K-wires have been removed; the arm has been placed across the chest, followed by canal drilling and now screw insertion



**Fig. 16.93** Mini C-arm positioning for lateral radiograph



**Fig. 16.94** Final intraoperative radiographs following ORIF utilizing a 7.3-mm screw to improve purchase



## 16.3 Patient Rehabilitation

The plan following surgery is similar for either the K-wire or 6.5-mm screw techniques. Immediately after surgery, the arm is placed in a long arm posterior splint for 2 or 3 days to allow soft tissue rest and avoid tension of the incision. The arm is elevated in a foam block. Depending on the bone quality, the patient is allowed full elbow range of motion with use of the arm and hand for activities of daily living, but no strengthening or weight-bearing. If there is a concern for the quality of fixation, a custom orthotic is fabricated, generally at 30°–45° of elbow flexion and worn at night for approximately 4 weeks. Strengthening begins 6–8 weeks following surgery. Weight-bearing is permitted at 3 months.

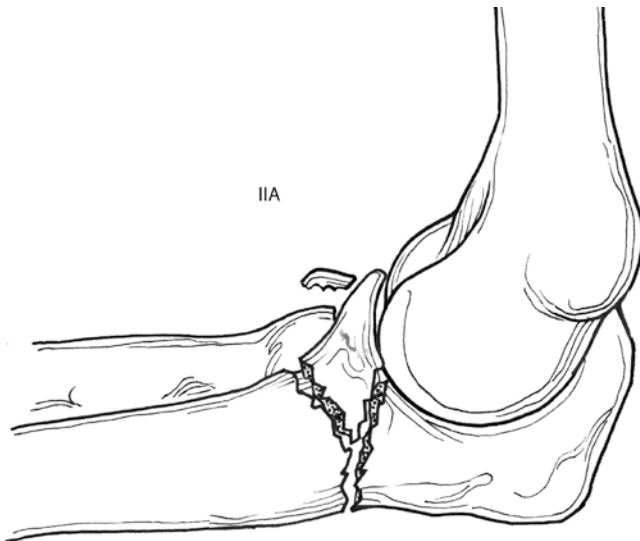
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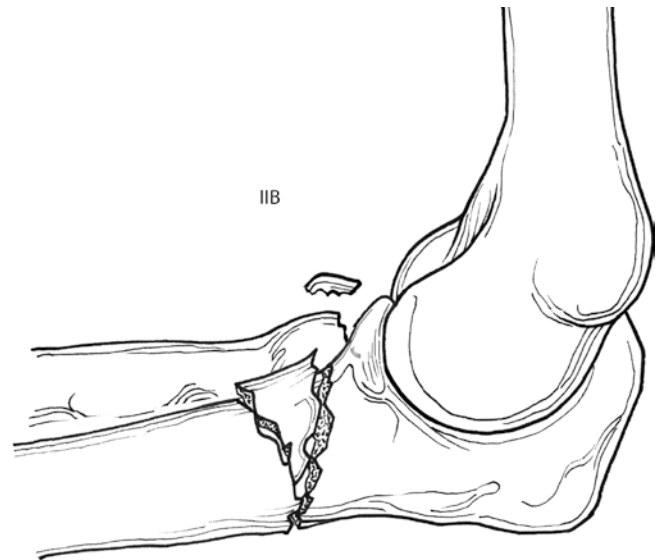
## 17.1 Transolecranon Fracture Dislocations Classifications

Transolecranon fracture dislocations have been given various names, including *Monteggia variants*, reflecting the association of the ulna fracture and the radial head dislocation [1–4]. The Bado classification also has been used to help

describe and classify these injuries. Of particular note is the association of the Bado type II posterior transolecranon fracture dislocation with an increased incidence of radial head fractures and worse outcomes [5]. Jupiter *et al.* [6] have divided the posterior Monteggia lesion into four groups: groups IIA to IID include an olecranon component (Figs. 17.1, 17.2, 17.3, and 17.4).

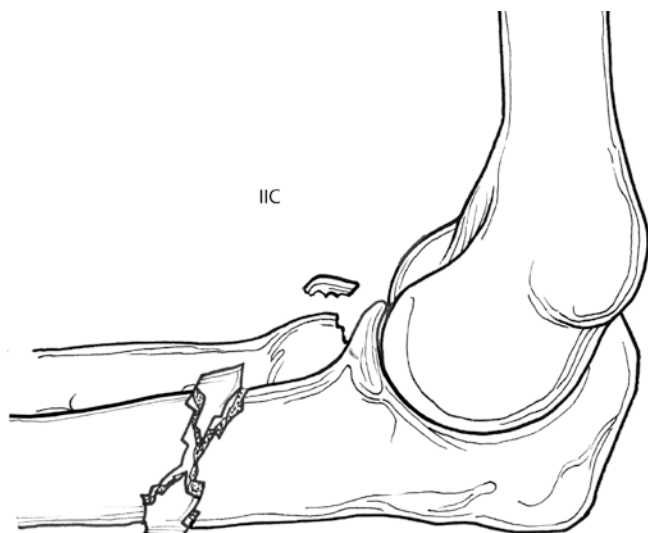


**Fig. 17.1** Posterior Monteggia Bado Type IIA

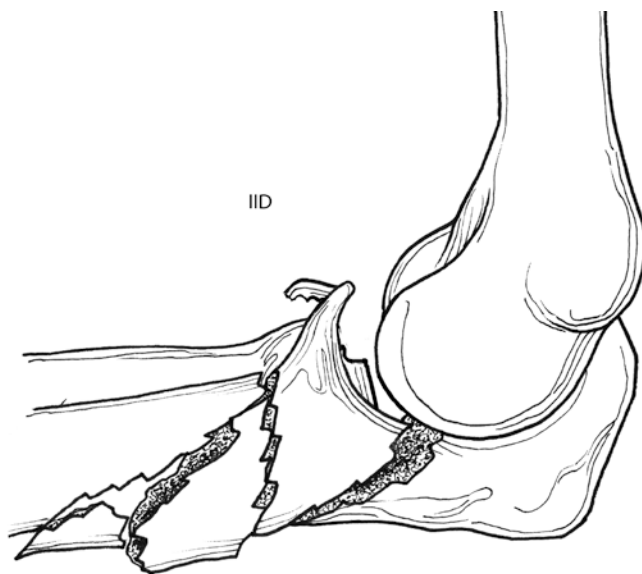


**Fig. 17.2** Posterior Monteggia Bado Type IIB





**Fig. 17.3** Posterior Monteggia Bado Type IIC



**Fig. 17.4** Posterior Monteggia Bado Type IID

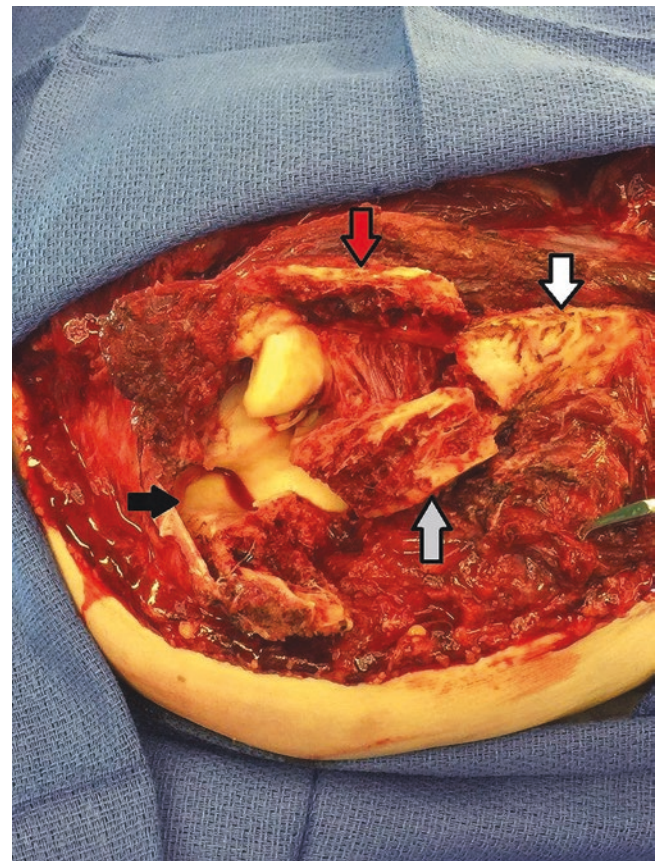
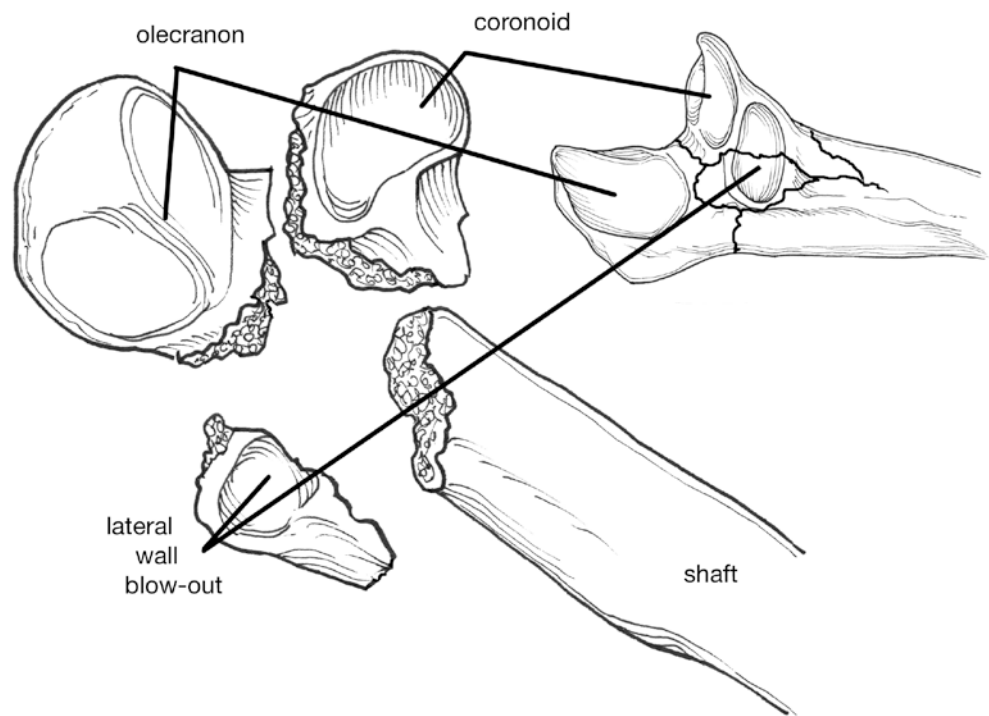
I tend to stick with the Bado classification and not use subgroups. Regardless of the direction of the radial head dislocation, there are usually four main identifiable fracture fragments: the olecranon process, the ulnar shaft, the coro-

noid, and the lateral wall blowout fragment, with the associated attached annular ligament and lateral collateral ligamentous complex (Figs. 17.5, 17.6, 17.7, and 17.8).



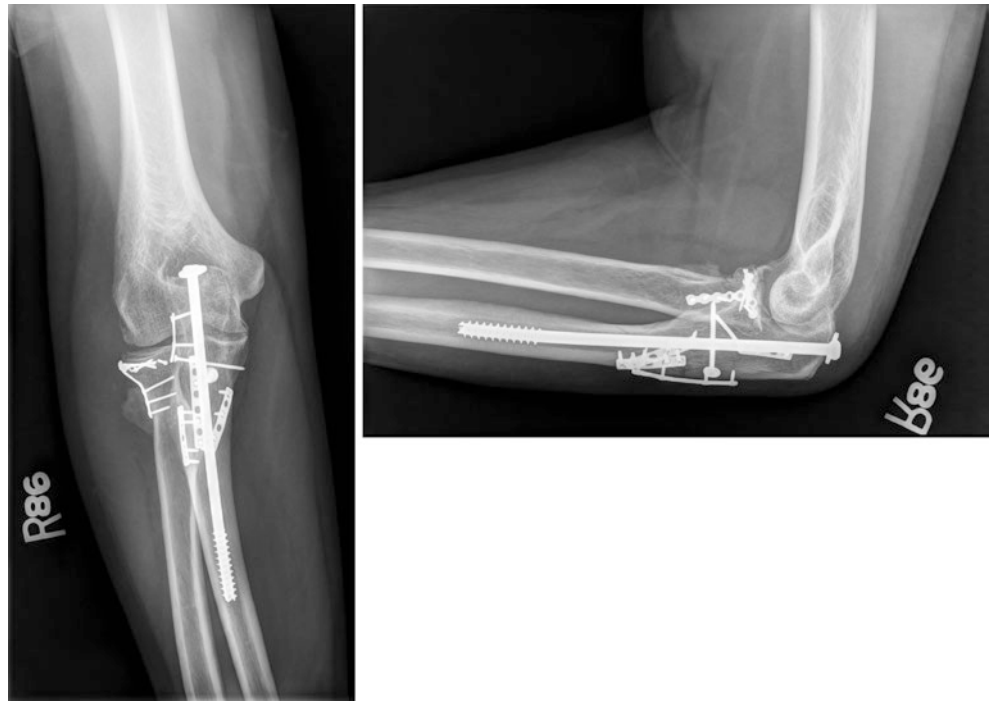
**Fig. 17.5** Injury radiographs of right elbow transolecranon fracture dislocation Bado Type II with four fragments: shaft, olecranon, coronoid, and lateral wall blowout fragment

**Fig. 17.6** Diagrammatic representation of the four components of the fracture dislocation



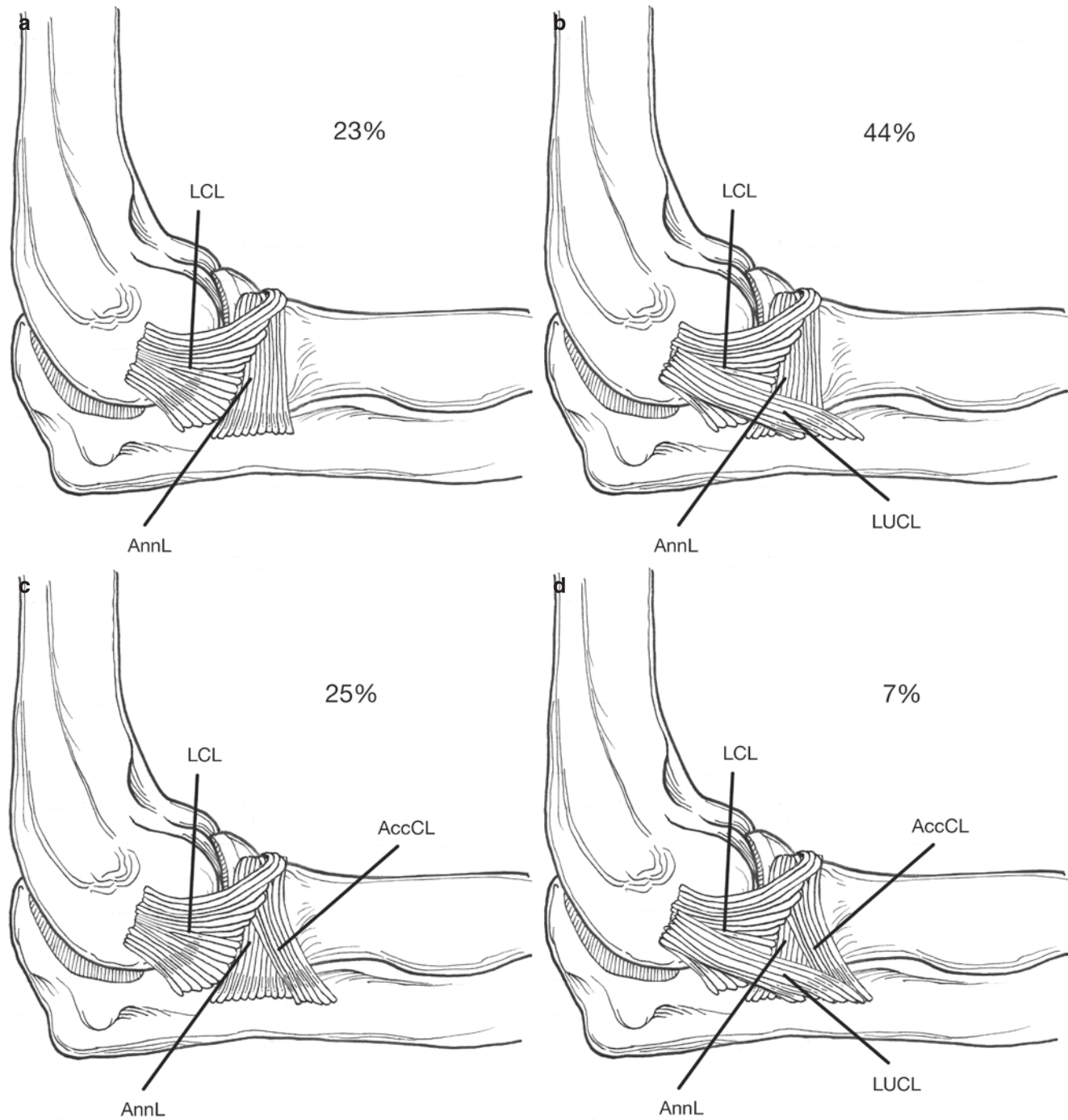
**Fig. 17.7** Intraoperative exposure with the four fragments identified: shaft (*white arrow*), olecranon (*black arrow*), coronoid (*grey arrow*), lateral wall (*red arrow*)

**Fig. 17.8** Radiographs at time of discharge, with each fragment addressed





The lateral ligament complex varies in make-up, with a lateral ulnar collateral ligament identified by Beckett *et al.* [7] in only about 50% of cases (Fig. 17.9).

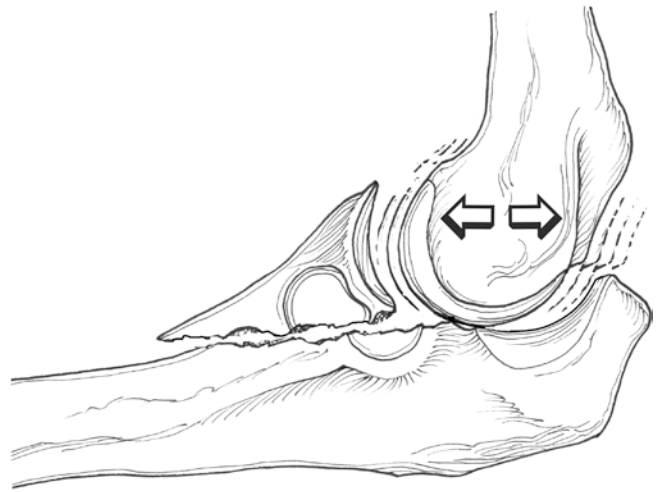


**Fig. 17.9** (a–d) Lateral ligamentous complex percentages

Therefore, I refer to the stabilizing structures laterally as the *lateral collateral ligamentous complex*.

## 17.2 Sequence of Fixations of Transolecranon Fracture Dislocation

The approach to the open reduction internal fixation (ORIF) of the transolecranon fracture dislocation is driven by the appreciation of the four fragments, with the fixation proceeding in an appropriate sequence. Regardless of the direction of the radial head dislocation or the number of fracture fragments, the reconstruction begins in the center of the elbow. You work out from the center of the elbow so as to not block your visualization of the deeper structure with reduced bone fragments [8, 9]. The importance of the coronoid fixation is reflected by the containment of the distal humerus in the proximal ulna and by the prevention of shearing, which occurs if the coronoid process is displaced distally because of inadequate reduction and fixation (Fig. 17.10).



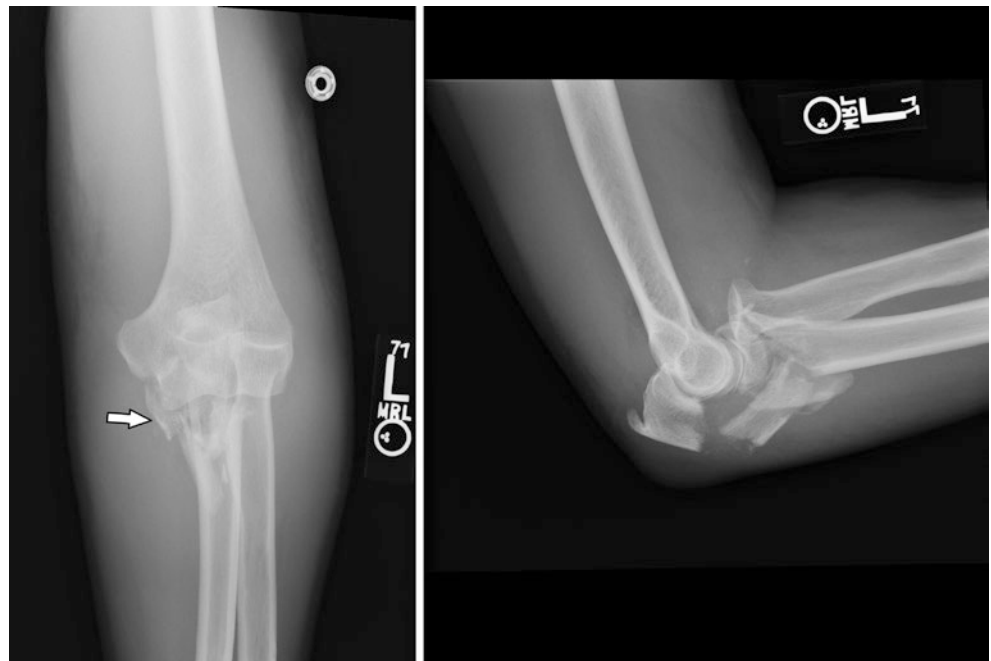
**Fig. 17.10** Displaced coronoid fragment allowing shearing of the distal humerus because of loss of containment

### 17.2.1 Patient Positioning and Surgical Approach

The patient is positioned supine with the top of the hand table aligned with the patient's axilla region. The patient's elbow should be resting at the center of the hand table, so that when the patient's elbow is flexed, the arm is internally rotated. A sterile tourniquet is used. I use a pneumatic tourniquet, as opposed to a roll-up tourniquet, because of concern that over-telescoping with the roll-up could create a secondary injury. Patient prep and draping are reviewed in Chap. 15.

With the patient in a supine position, as opposed to a lateral position, I find it easier to approach the lateral aspect of the elbow via direct anterior joint visualization; otherwise, I would need to address the intra-articular involvement of an arm that is upside down. With elbow flexion, shoulder abduction, and external rotation, access to the medial fragments and larger coronoid fragments can be attained. The medial approach also allows access to the medial facet fragment of the coronoid complex, with the medial collateral ligament attachment (Figs. 17.11 and 17.12).

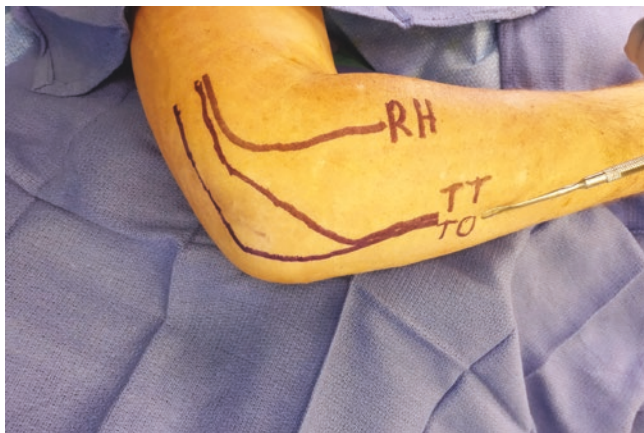
**Fig. 17.11** Injury radiographs of a left elbow Bado Type I transolecranon fracture dislocation with medial facet fragment (arrow)





**Fig. 17.12** Intraoperative radiograph demonstrating inclusion of medial facet fixation

The incision is posterolateral, extending proximal to the tip of the olecranon by 4–5 cm, and then along the subcutaneous border of the ulna (Fig. 17.13).

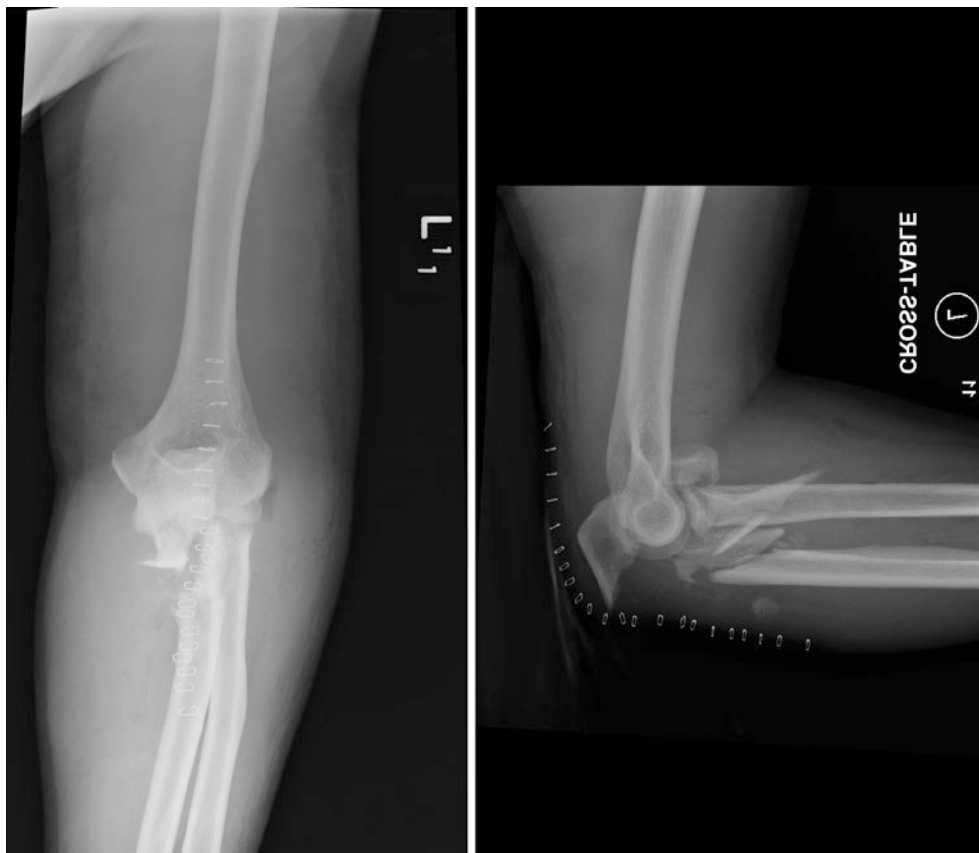


**Fig. 17.13** Transolecranon incision

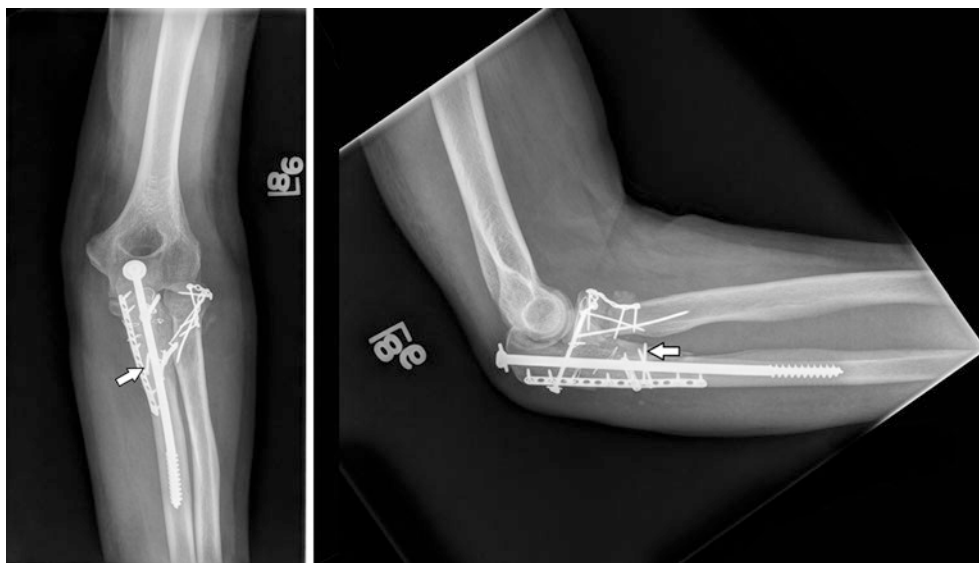
The incision is continued distally from the border of the ulna, adequate to allow mini-fragment plate fixation. My preference is to use an intramedullary device as definitive fixation; using a plate instead would be cause for concern about soft tissue and the implications of a larger, bulkier plate on the subcutaneous portion of the ulna. I also find that using an intramedullary technique allows the ulna to be effectively reconstructed, first with unicortical mini-fragment plates, interosseous wires, and unicortical lag screws, and then by the definitive fixation (Figs. 17.14 and 17.15).



**Fig. 17.14** Radiographs on presentation of left elbow fracture dislocation after patient referral for open reduction internal fixation (ORIF)



**Fig. 17.15** Intraoperative radiographs following ORIF utilizing interosseous wire, unicortical lag screws (arrow), and mini-fragment plates



With the incision outlined, the arm is elevated and exsanguinated, and the tourniquet is inflated. The elbow is then rested on a small, one-gown to two-gown bump. Following the incision, the lateral skin flap is elevated over the anconeus and the lateral epicondyle (Fig. 17.16).



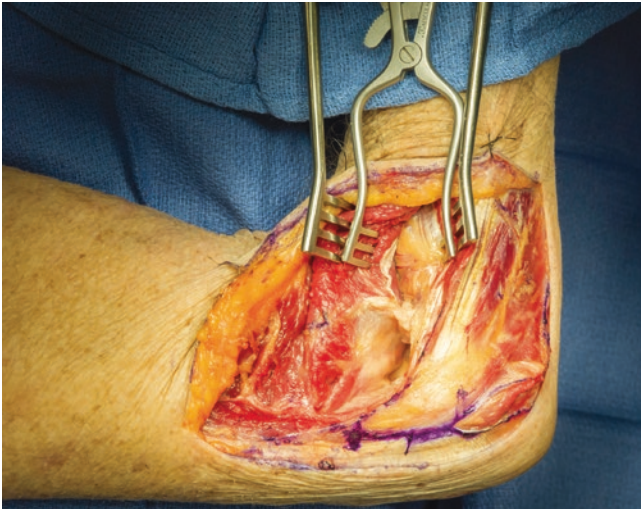
**Fig. 17.16** Lateral flap elevated over lateral epicondyle and forearm fascia. An inverted Y incision outline of anterior approaches is required for radial head fixation or replacement

The posterior radial collateral or radial recurrent vessels may or may not need to be divided, depending on the need to address the radial head. In Bado Type II posterior dislocations, the radial head frequently can be telescoped through the posterior defect. To allow additional access, the lateral wall fragment with the attached annular ligament can be retracted.

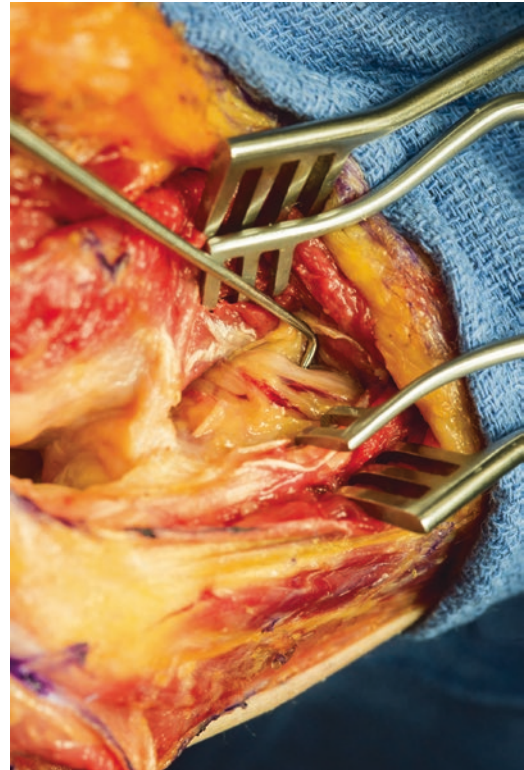
If an anterior approach is needed, then the incision and subcutaneous dissection will need to course anterior to the lateral epicondyle. I prefer to come along the supracondylar ridge, anterior to the leading edge of the lateral collateral ligamentous complex, anteriorly retracting the extensor carpi radialis brevis (ECRB), and possibly even dividing a portion of the supinator, depending on the access needed to the radial head and neck (Figs. 17.17, 17.18, 17.19, and 17.20).



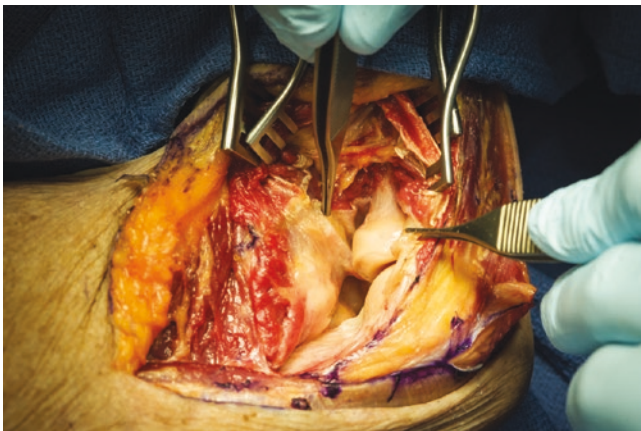
**Fig. 17.17** Anterior approach to the radial head



**Fig. 17.18** Anterior approach if plating of radius is required, beginning with split in the extensor carpi radialis brevis (ECRB) fascia



**Fig. 17.19** Posterior interosseous nerve exposed



**Fig. 17.20** Annular ligament divided to gain access to the radial neck



With the anconeus elevated, and depending on the involvement of the olecranon process, I try to at least partially preserve the relationship of the anconeus to the triceps, in an effort avoid denervating the anconeus. The dissection elevates the anconeus subcutaneously, continuing distally



**Fig. 17.21** Posterolateral approach between the anconeus and triceps, excising the posterolateral capsule

Frequently there are numerous fragments, though I have described four. The four major fragments described should be most appreciated.

With the arm externally rotated and abducted and the elbow flexed, the medial approach can be performed and the ulnar nerve may be visualized, but the nerve is not routinely dissected, depending on the zone of injury and the need of positioning the fixation. With the larger coronoid fragments, fixation from the medial side will frequently be required, as this is where the best keys are. Once you have completed the fracture exposure and interrogated the fracture to learn its personality, a few questions and consequent issues need to be addressed. Acknowledging the importance of the ulnohumeral articulation and the need to work from the center of the elbow out, some steps need to be established.

### 17.3 Fixation Issues and Options

Unfortunately, I don't have a definitive answer for every fracture, but I can identify major issues and offer options for the fixation procedure:

- Coronoid fracture issues
  - Is it segmental?

and elevating the extensor carpi ulnaris (ECU) as needed. Care must be given to the lateral wall blowout fragment in an effort to preserve the annular ligament and bone attachments (Figs. 17.21 and 17.22).

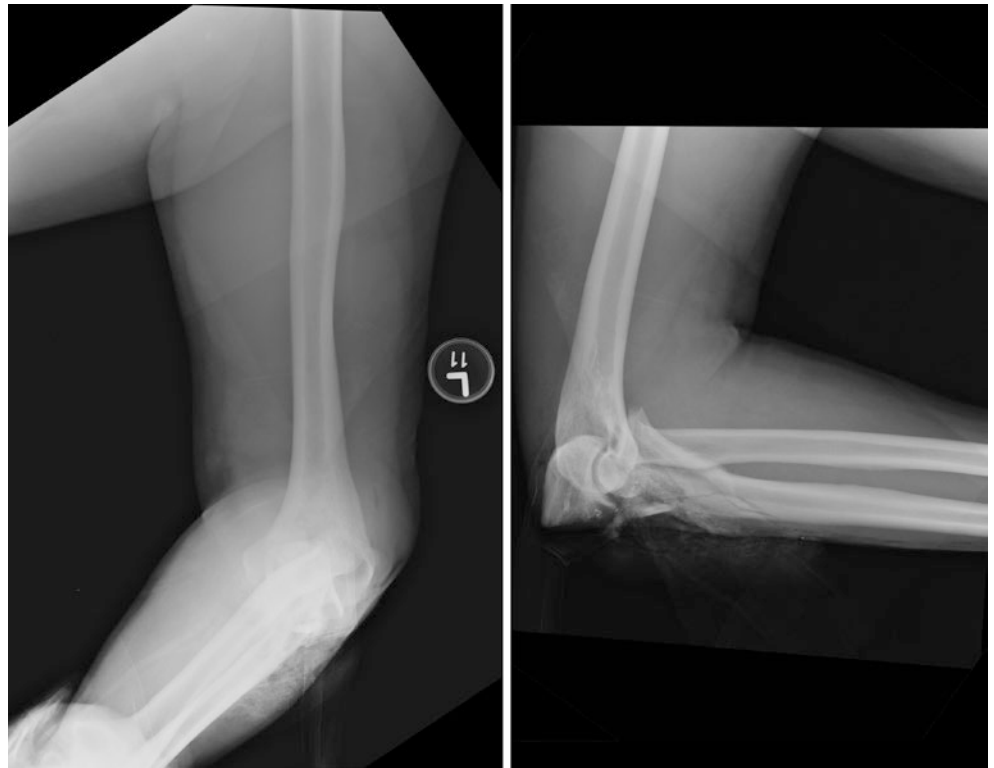


**Fig. 17.22** View into the ulnohumeral and radiocapitellar joint

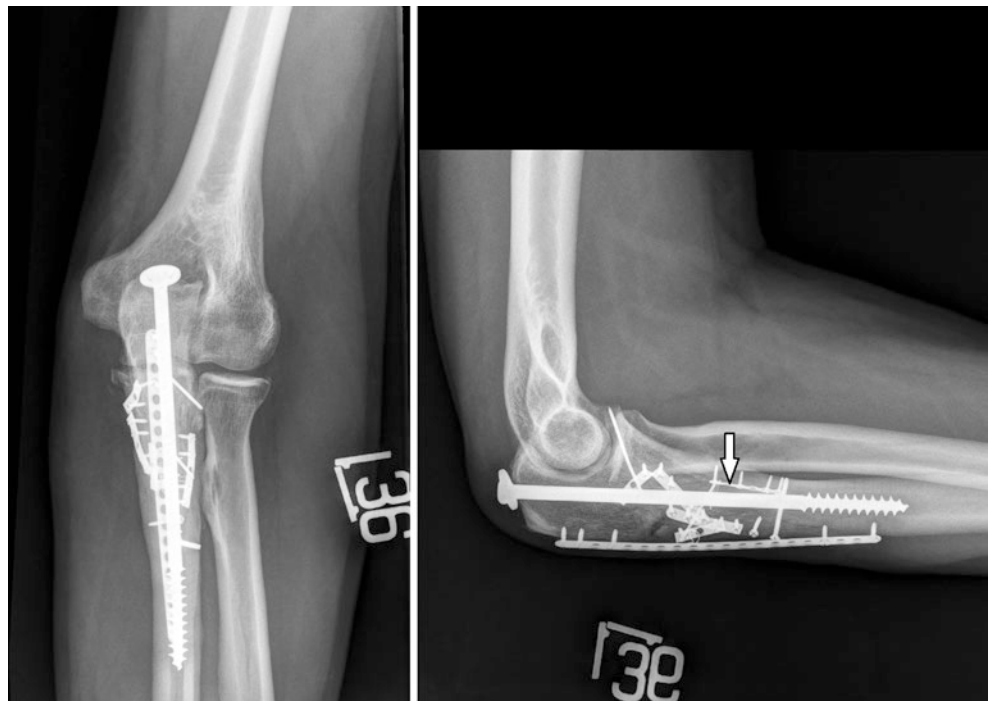
- Should it be reduced first to the shaft or first to the olecranon?
- Radial head issues
  - Is it anteriorly or posteriorly dislocated?
  - If anterior, do I need another venue for access, such as an anterior approach?
  - Does it get fixed or replaced?
  - If posterior, can its fixation be performed in the dislocated position, followed by reduction to the capitellum?
- Lateral wall blowout fragment issues
  - Does the fragment need to be reduced and stabilized to the coronoid/shaft complex and then stabilized to the olecranon?
  - Or can the fragment be used to bridge the shaft and olecranon once the reduction has been performed?
- Multiple fragments issues
  - Are there multiple fragments that need to be built up in order to get to the four major fragments?

To deal with small fragments, use 24-gauge and 26-gauge interosseous wires. Use 1.5-mm and 2-mm mini-fragment plates in a unicortical fashion to avoid cluttering the canal with screws and fixation that would block the intramedullary device. Endosteal plates can be used to try to prevent anterior soft tissue stripping, particularly when dealing with a comminuted coronoid and shaft (Figs. 17.23 and 17.24).

**Fig. 17.23** Injury radiographs of left elbow open fracture dislocation

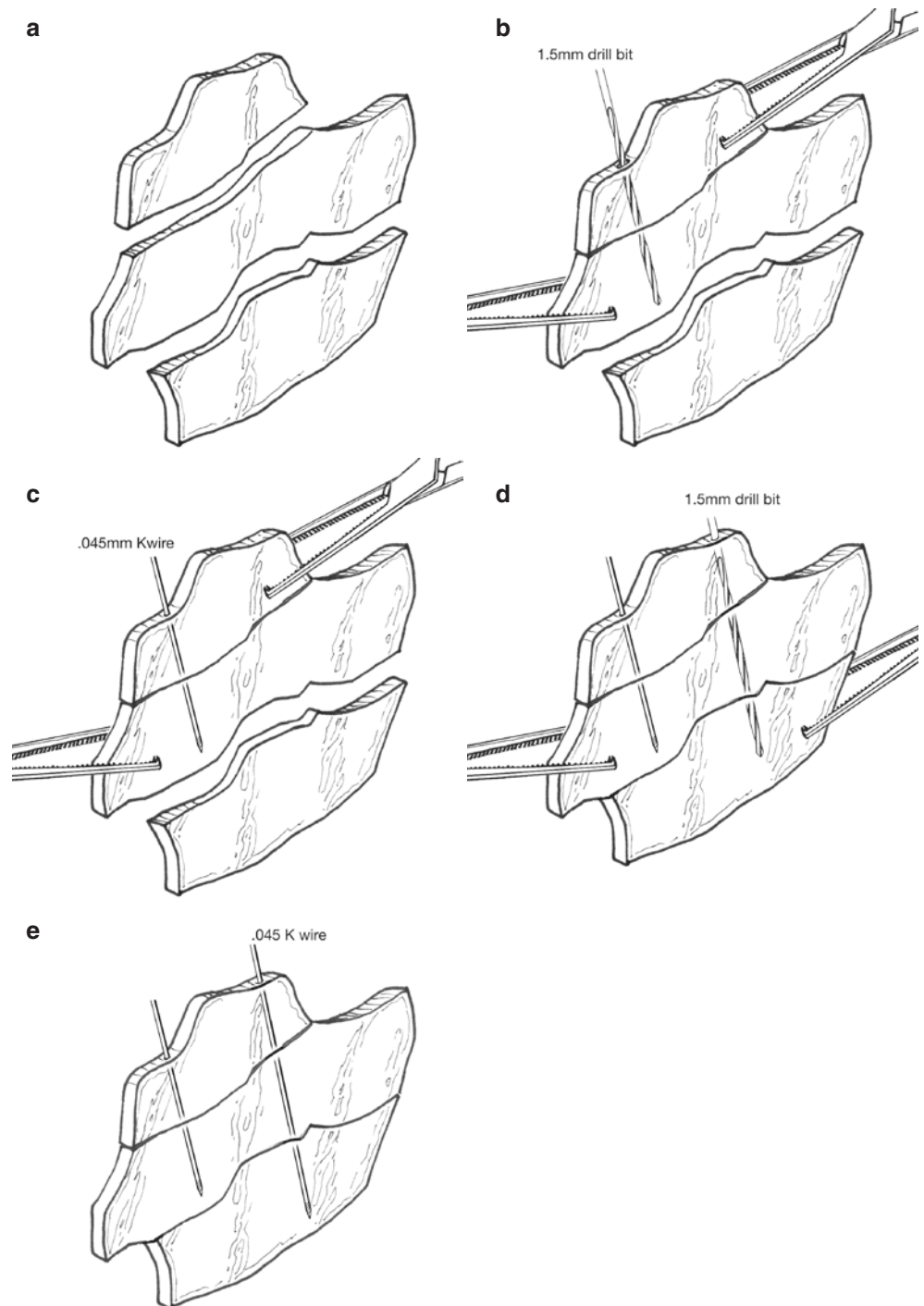


**Fig. 17.24** Follow-up radiographs demonstrating endosteal plate and unicortical screw



Stacking fragments with intracortical Kirschner wires (K-wires) can be helpful (Fig. 17.25).

**Fig. 17.25** A-E Sequence of steps in stacking fragments using predrilling with a drill bit followed by insertion of Kirschner wire (K-wire). Predrilling decreases thermal necrosis when drilling with a K-wire

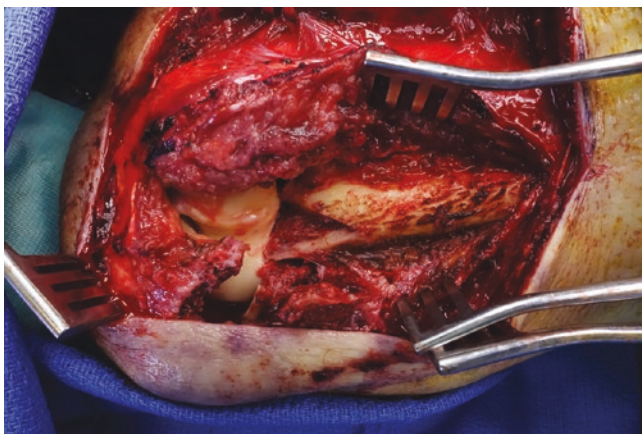
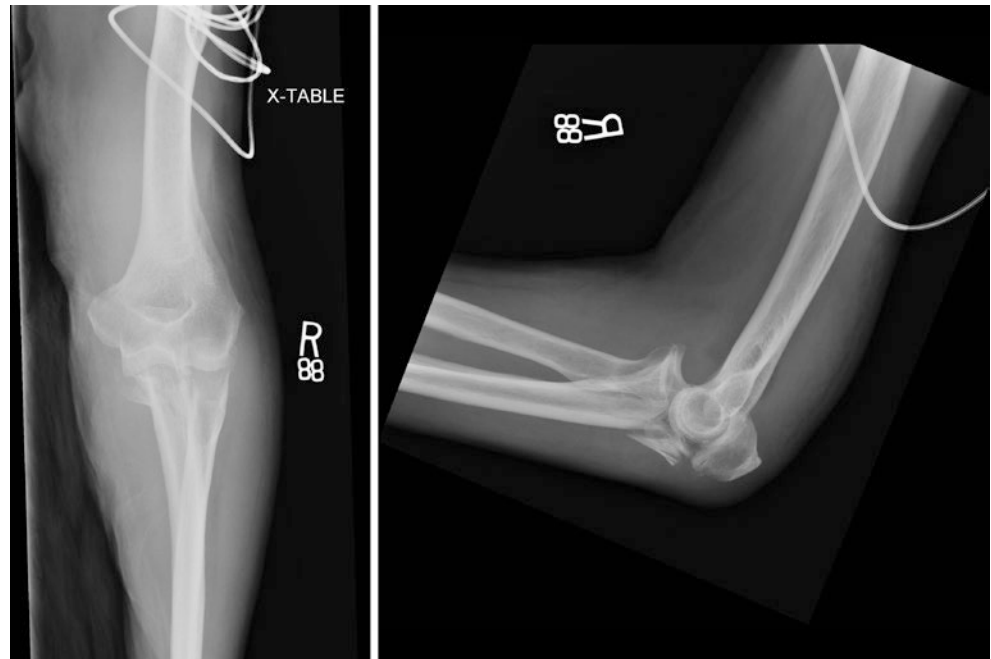




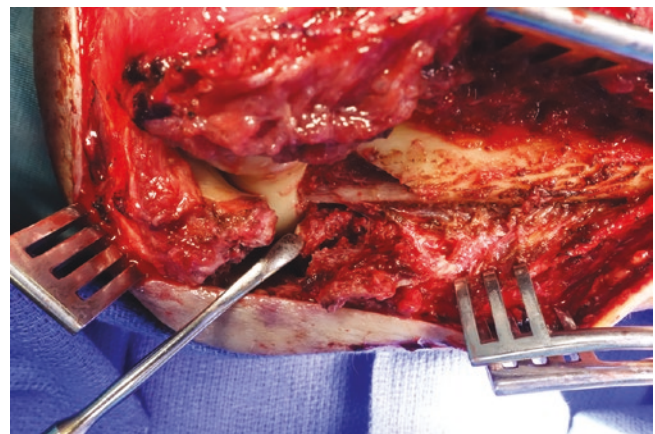
(These techniques are not specific to transolecranon fracture fixation). After deciding the sequence of steps, usually the coronoid is fixed to the shaft using anterolateral keys or

medial proximal cortical keys. Sometimes the cancellous keys help as well (Figs. 17.26, 17.27, 17.28, 17.29, 17.30, 17.31, 17.32, and 17.33).

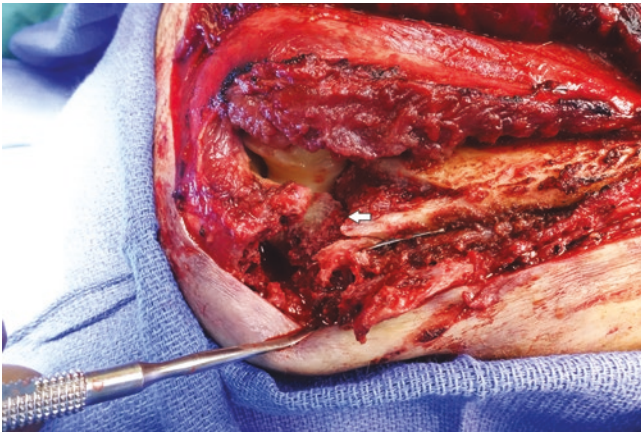
**Fig. 17.26** Injury radiographs of right Bado Type I anterior fracture dislocation, with intercalated articular fragment



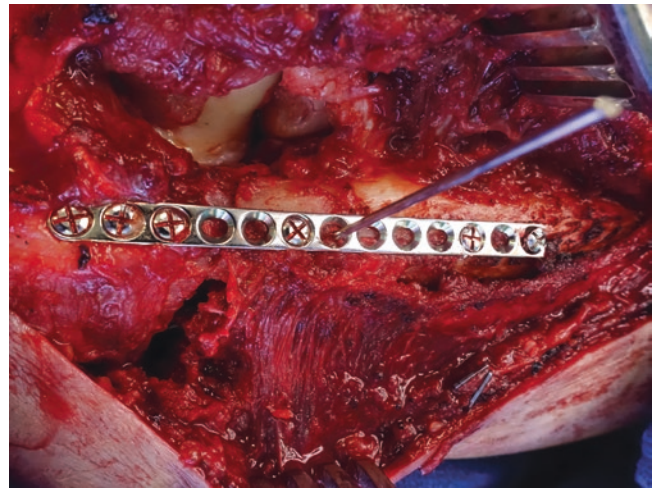
**Fig. 17.27** Exposure prior to reduction with intercalated intra-articular fragment



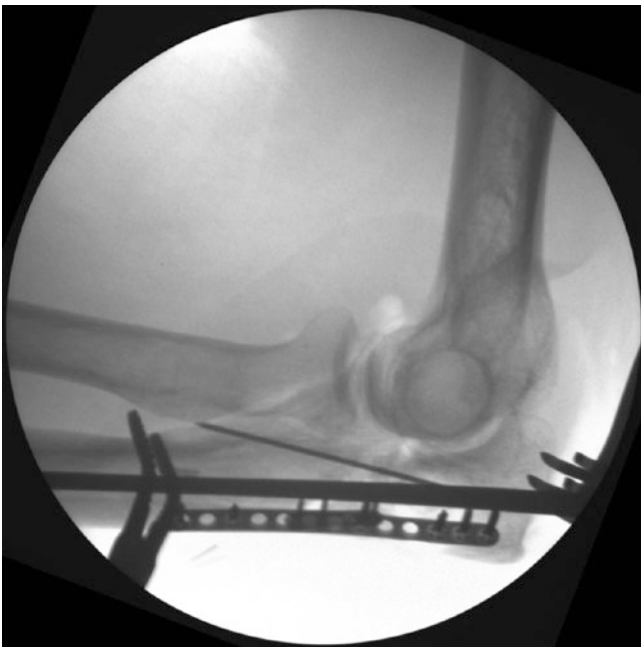
**Fig. 17.28** Fragment mobilized



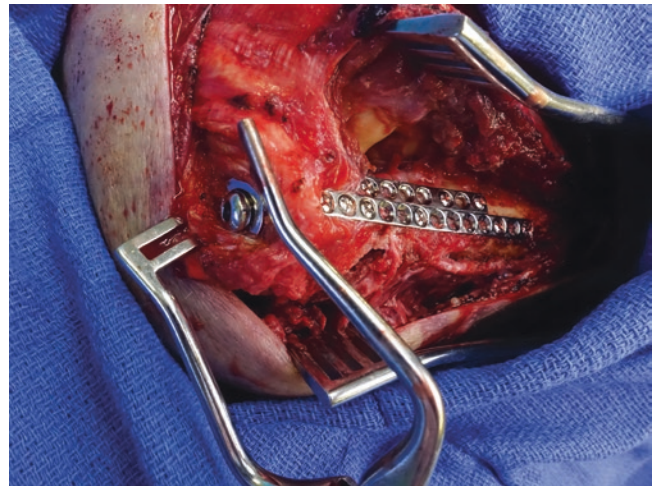
**Fig. 17.29** Fragment (*arrow*) reduced using cancellous keys with provisional fixation by K-wire and medial mini-fragment plate



**Fig. 17.30** Reduction of olecranon to shaft with 2.0-mm plate laterally



**Fig. 17.31** Intraoperative radiograph of right elbow with K-wire holding intercalated fragment reduced using cancellous keys



**Fig. 17.32** Definitive fixation, with K-wire removal



**Fig. 17.33** Intraoperative radiograph following ORIF

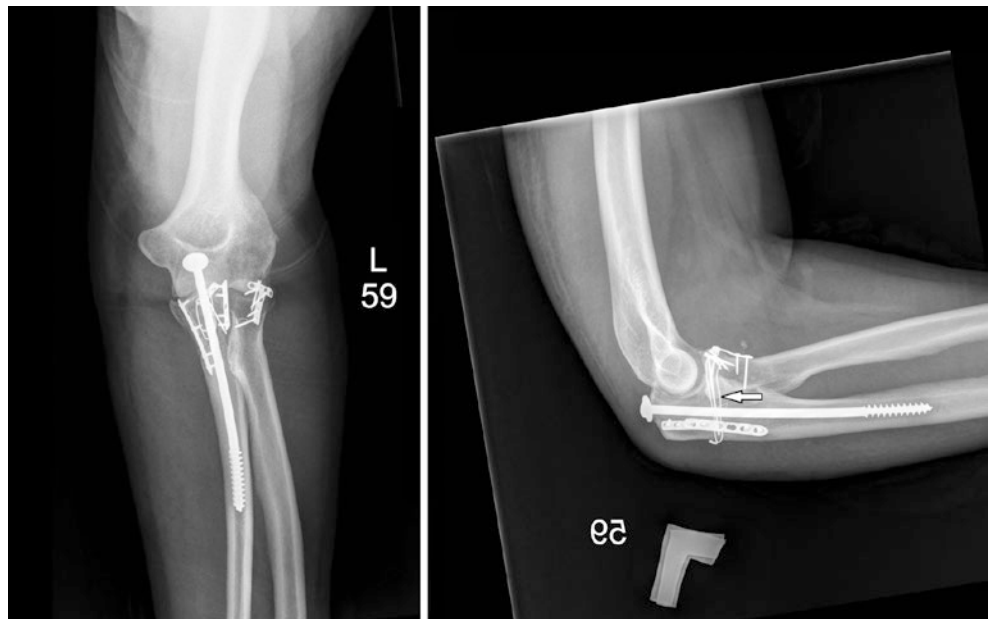


The coronoid may be segmental, and the fracture fragments need to be stacked (Figs. 17.34 and 17.35).

**Fig. 17.34** Injury radiographs of left elbow posterior fracture dislocation



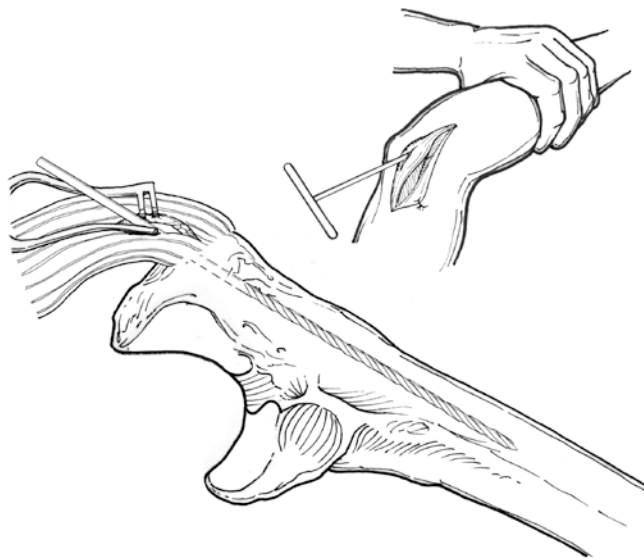
**Fig. 17.35** Follow-up radiographs demonstrating interosseous wire loop (arrow) securing stacked coronoid



In transolecranon fractures, the coronoid fragment or fragments tend to be larger and have better cortical keys medially, whereas the terrible triad has smaller tip avulsions that can be addressed anteriorly. Following the radial head fracture fixation or replacement, reduction of the radiocapitellar joint helps with reduction of the olecranon, which can then be provisionally fixed with a longitudinal K-wire or mini-fragment plate. The lateral wall blowout fragment will now bridge the coronoid shaft distally to the olecranon proximally. The fixation is generally first in the olecranon process because the bone quality is usually poorer than the bone quality lower on the shaft. You want to utilize your screws in weaker bone for one purpose only: plate to bone fixation, as opposed to using screws for the dual purpose of plate fixation to bone and cortical compression.

For insertion of the 6.5-mm screw or OlecranonNail® (Mylad Orthopaedic Solutions, McLean, VA), position the patient's arm across the patient's chest, resting it on a three-gown bump with the mini C-arm in a horizontal position. With the olecranon process now reduced and held with mini-fragment fixation, the triceps is split; pre-drilling is carried out with a 3.2-mm drill bit, followed by an over-drill with a 4.5-mm drill bit. Then, if the 6.5-mm screw is used, tap with

attention to prevention of torquing of the olecranon process (Fig. 17.36).



**Fig. 17.36** Forearm stabilization to prevent torquing during tapping

For a coronoid fracture, OlecranonNail® affords fixation through the nail (Figs. 17.37 and 17.38).



**Fig. 17.37** Injury radiographs of open left elbow anterior fracture dislocation

**Fig. 17.38** Follow-up radiographs following ORIF with olecranon. Note use of wrist fusion plate for radius ORIF



Once the guidewire for the OlecranonNail® has been inserted, over-drill, and then give close attention to positioning the nail distally to allow purchase of the coronoid process. If the coronoid process is small, I use either a 20- or 22-gauge wire loop or a #5 Ethibond® suture. If an Ethibond® suture is used, care must be taken in the intramedullary drilling, reaming, and screw insertion, so as to not cut the suture. Therefore, 24-gauge wires can be used as loops, then canal preparation, with implant insertion followed by delivering the transosseous suture dorsally to be tied over the cortex. This technique is used more for the tip or avulsion injuries. The longitudinal screw is advanced further down the shaft, where it is important to gain endosteal purchase. One of the concerns has been over-compression; visualization of the fracture interdigitation is important to avoid fracture buckling.

Allografting also can be carried out, and in an acute, open setting I will do this, mixing the bone graft with vancomycin. The final step is to tie the Ethibond® coronoid suture, if utilized, after fixation of the shaft. Once fixation is completed, the closure is carried out with buried 2-0 polydioxanone (PDS®) sutures from distal to the level of the epicondyle, including the triceps insertion, and then skin closure over a medium HemoVac® drain. The splint posi-

tioning postoperatively is generally at 90° because I do not want to stress the coronoid fixation in a shearing fashion with elbow extension.

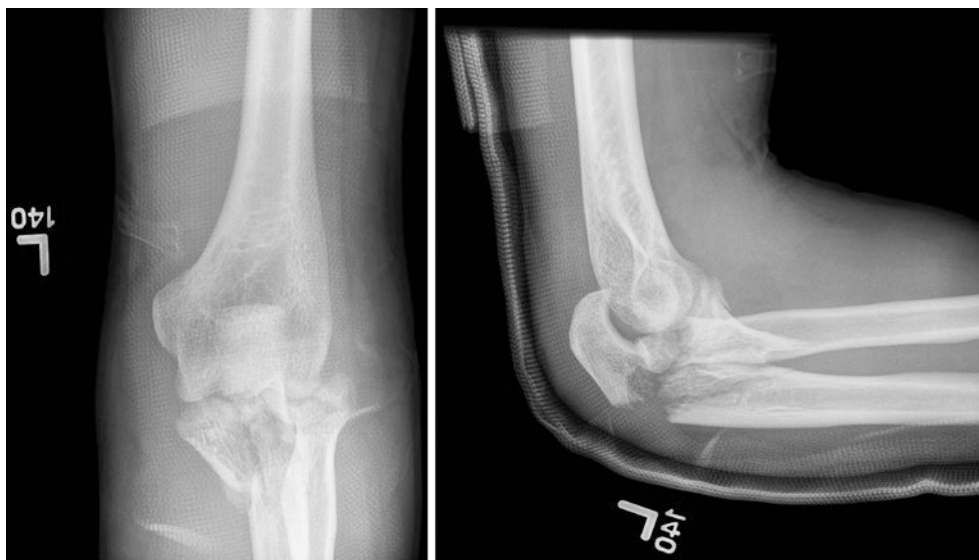
## 17.4 Summary of Steps

1. Exposure and fracture preparation: Learn the personality of the fracture for subsequent fixation
2. Coronoid: fixation to either the shaft or olecranon
3. Radial head: ORIF or replacement, followed by reduction.
4. Shaft/coronoid complex reduced to olecranon or coronoid/olecranon complex, reduced to shaft
5. Lateral wall blowout fragment: fixation or completion of fixation
6. Definitive fixation with intramedullary device

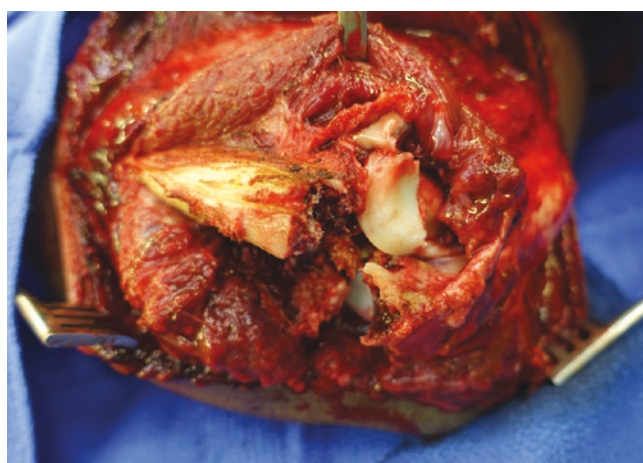
Figures 17.39, 17.40, 17.41, 17.42, 17.43, 17.44, 17.45, 17.46, 17.47, 17.48, 17.49, 17.50, 17.51, 17.52, 17.53, 17.54, 17.55, 17.56, 17.57, 17.58, 17.59, 17.60, 17.61, 17.62, 17.63, and 17.64 illustrate many of these steps.



**Fig. 17.39** Injury radiographs following referral for left elbow transolecranon fracture dislocation (Bado Type II)



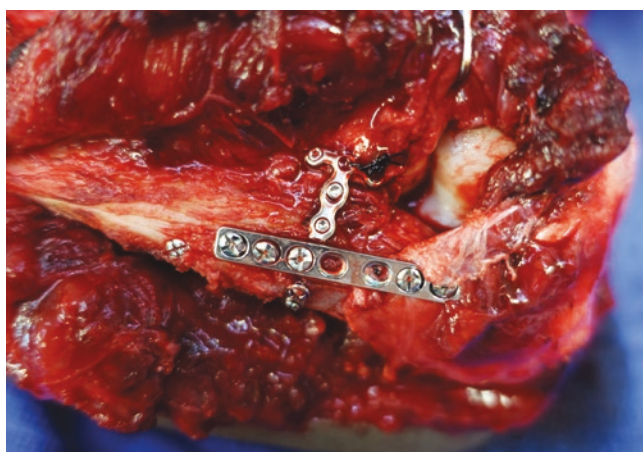
**Fig. 17.40** Characteristic traumatic rent in anconeus and fascia



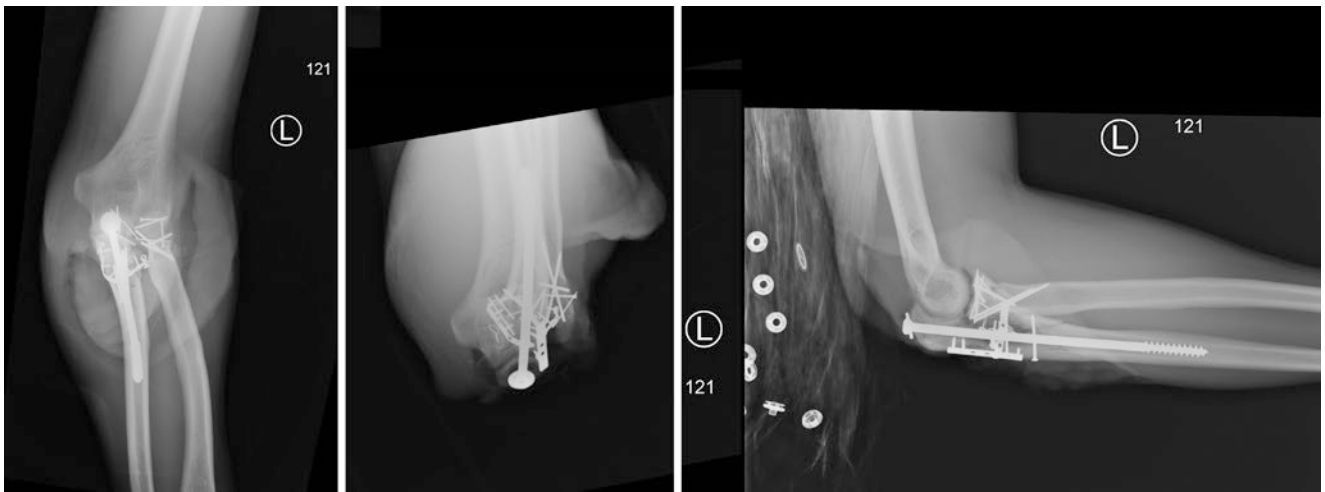
**Fig. 17.41** Fracture preparation with posterior radial head fracture dislocation



**Fig. 17.42** Fixation in posterior dislocation position

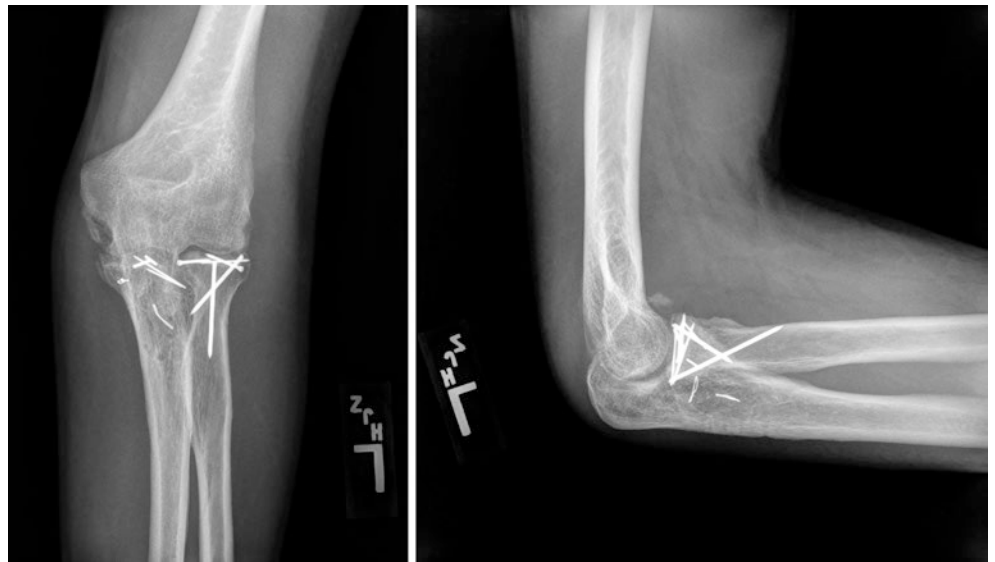


**Fig. 17.43** Provisional fixation completed, including 1.5-mm locking T plate and PDS® sutures in annular ligament and lateral wall fragment



**Fig. 17.44** Intraoperative radiographs following ORIF

**Fig. 17.45** Radiographs following capsulectomy and hardware removal



**Fig. 17.46** Injury radiographs on presentation of left elbow transolecranon fracture dislocation (Bado Type II)







**Fig. 17.47** Skin incision outlined for left elbow transolecranon fracture dislocation



**Fig. 17.48** Flap elevated with secondary fascial incisions outlined



**Fig. 17.49** Deeper approach to coronoid and radial head



**Fig. 17.50** Freer moving radial head, exposing coronoid fracture (star)

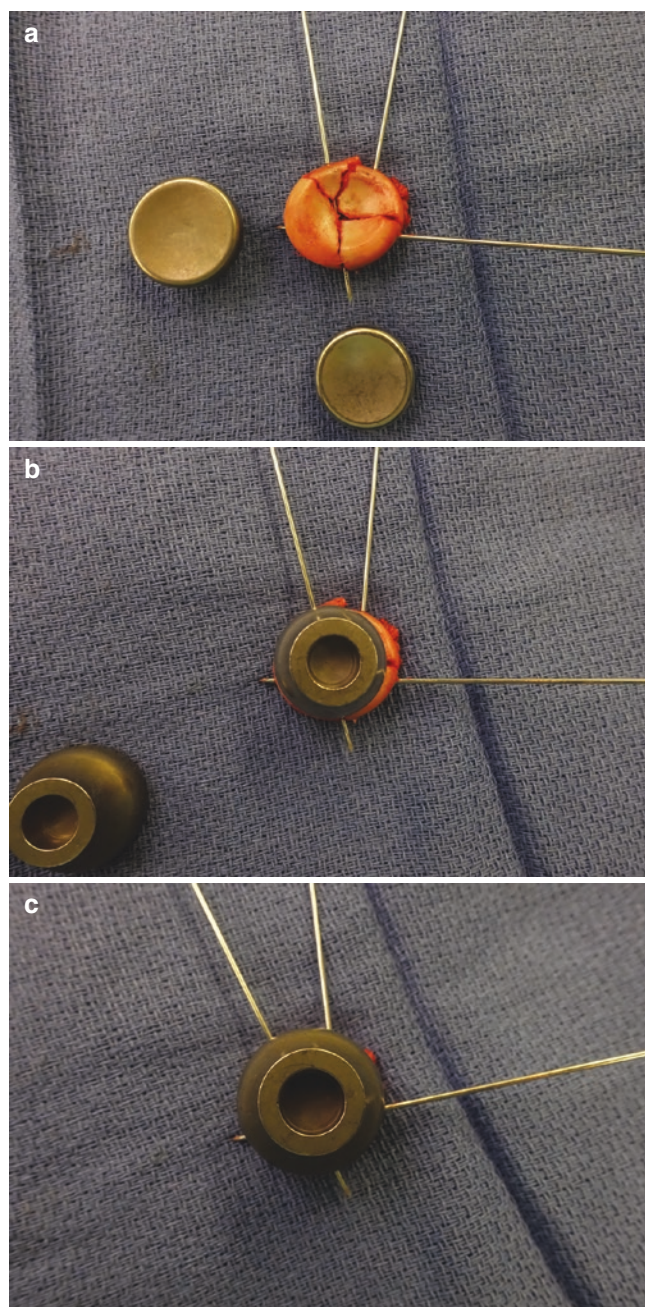


**Fig. 17.51** Radial head fracture demonstrating four major fragments; bone quality for ORIF is concerning





**Fig. 17.52** Broaching canal after osteotomy of radial neck through posterior dislocation



**Fig. 17.53** (a) Radial head sizing. (b) Slightly undersized trial selected. (c) Too big





**Fig. 17.54** Height selection



**Fig. 17.55** Implant and assembly device



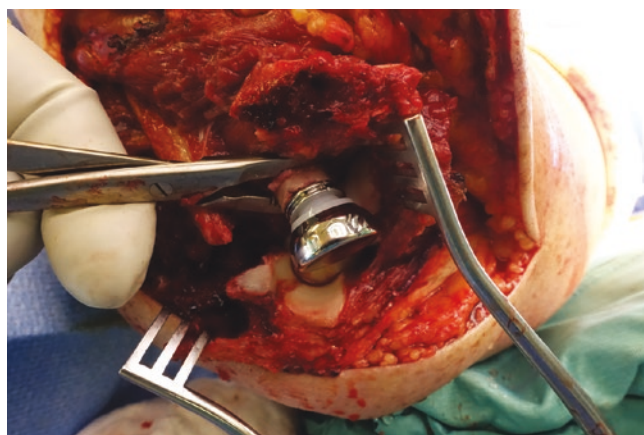
**Fig. 17.56** Bipolar head



**Fig. 17.57** Implant snapped together



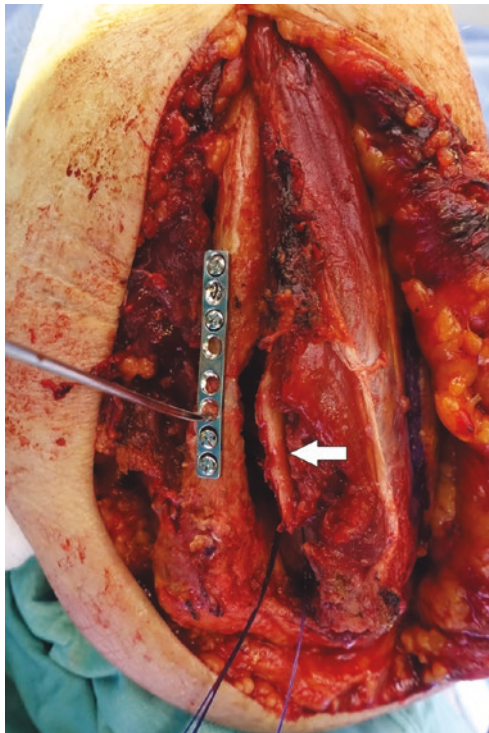
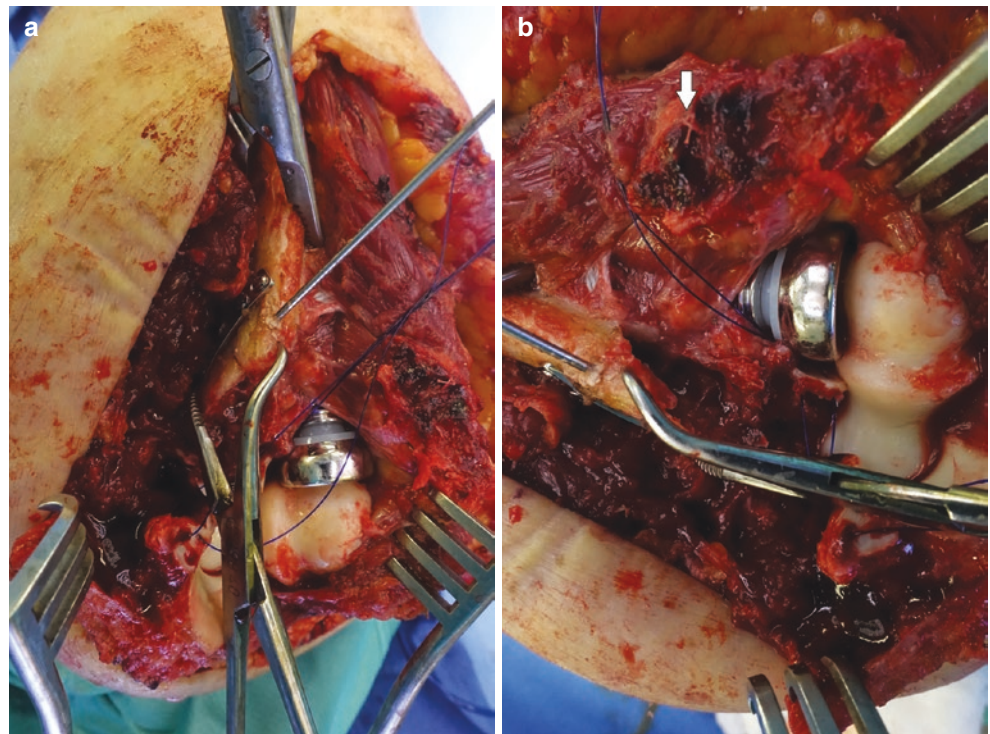
**Fig. 17.58** Canal prepared



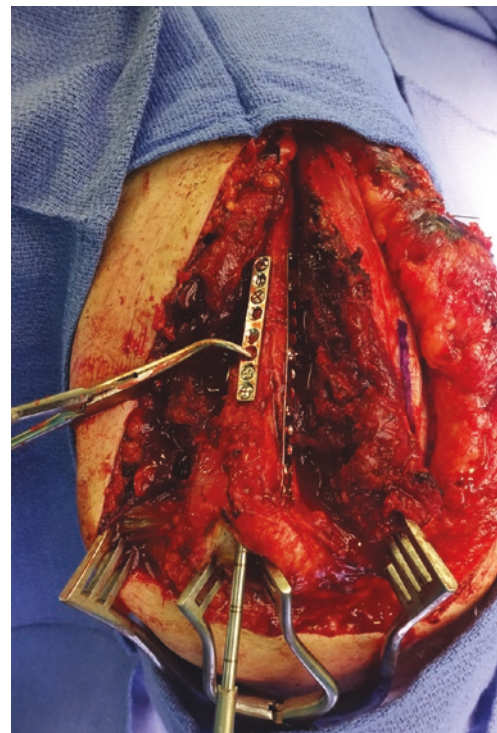
**Fig. 17.59** Implant inserted and seated



**Fig. 17.60** (a) Radial head reduced; sutures in chondral fragments to be tied after reduction of ulna. (b) Sutures in sigmoid notch chondral fragment and lateral wall blowout fragment (*arrow*)

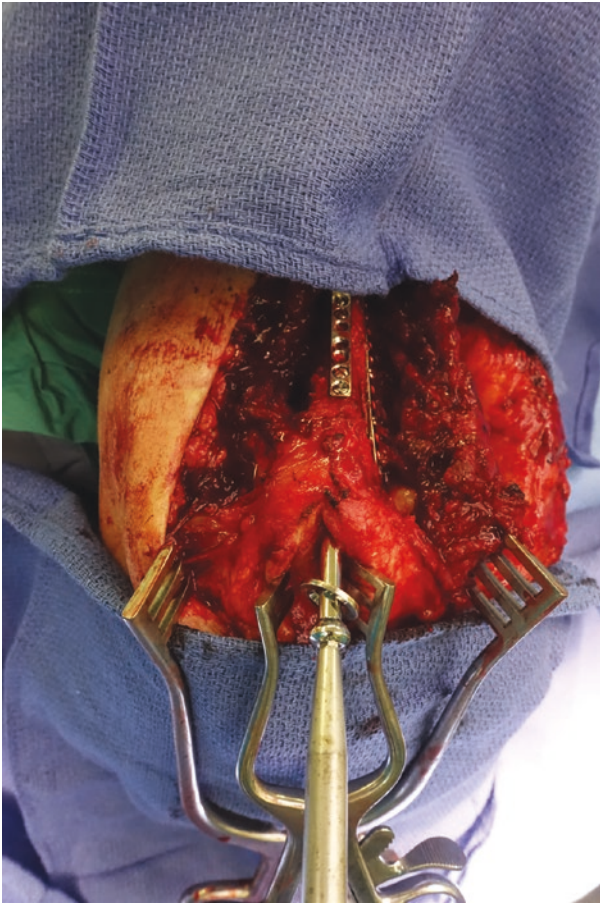


**Fig. 17.61** Olecranon reduced to shaft/coronoid with dorsal 2.0-mm mini-fragment plate. Lateral wall fragment (*arrow*)

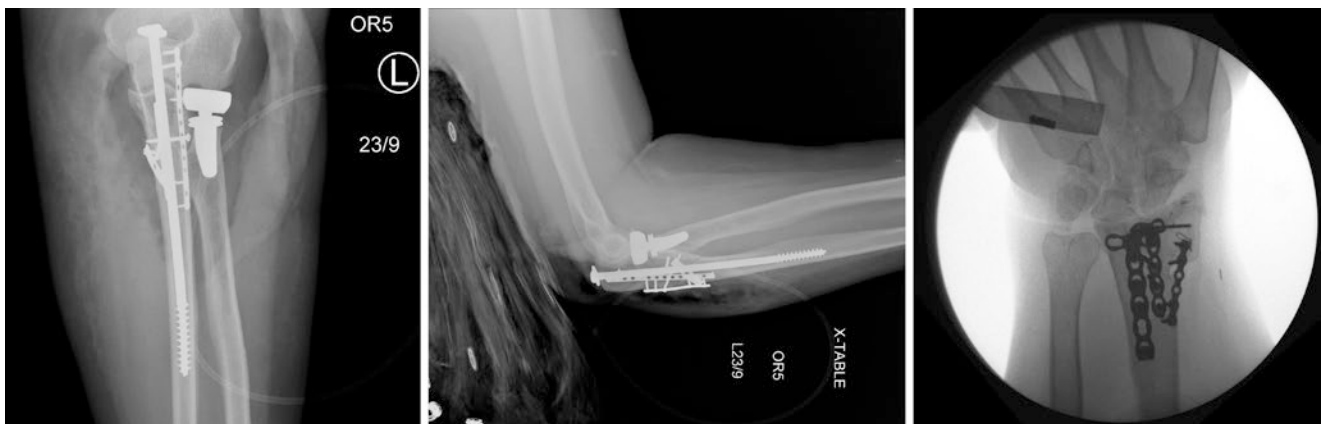


**Fig. 17.62** Lateral wall fragment reduced and held with long 2.0-mm plate with drilling with 3.2-mm drill bit, followed by a 4.5-mm bit, then tapping with a 6.5-mm tap





**Fig. 17.63** 6.5-mm screw insertions



**Fig. 17.64** Intraoperative radiographs following ORIF and radial head replacement, including wrist radiograph to calculate ulnar variance

## 17.5 Patient Rehabilitation

Generally, the patient is allowed full pronation and supination at 90°, and, depending on the degree of fixation, beginning with 60° of extension to full flexion, 15° of extension is added each week. There should be no weight-bearing for 3 months, but strengthening typically can start at 6–8 weeks. Dynamic splinting can also be performed, if required, at 6–8 weeks.

## References

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2. Givon U, Pritsch M, Levy O, Yosepovich A, Amit Y, Horoszowski H. Monteggia and equivalent lesions. A study of 41 cases. *Clin Orthop Relat Res.* 1997;337:208–15.
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8. Doornberg J, Ring D, Jupiter JB. Effective treatment of fracture dislocations of the olecranon requires a stable trochlear notch. *Clin Orthop Relat Res.* 2004;429:292–300.
9. Beingessner DM, Nork SE, Agel J, Viskontas D. A fragment specific approach to Type IID Monteggia elbow fracture dislocations. *J Orthop Trauma.* 2011;25:414–9.

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### 18.1 Non-operative or Operative Radial Head Treatment

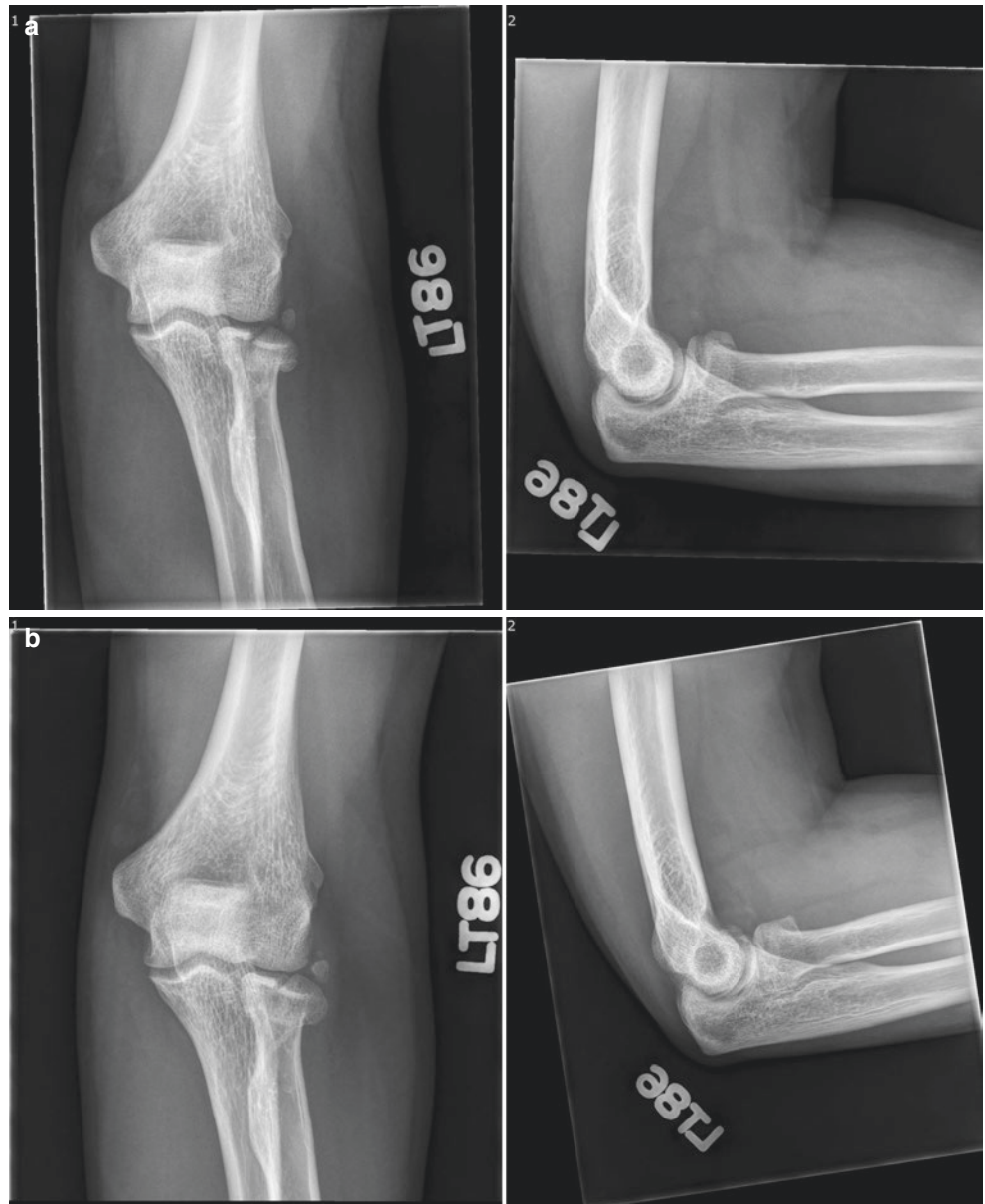
Are we going to fix or are we going to replace the radial head? This is the question frequently asked by the resident when the patient presents with a radial head fracture.

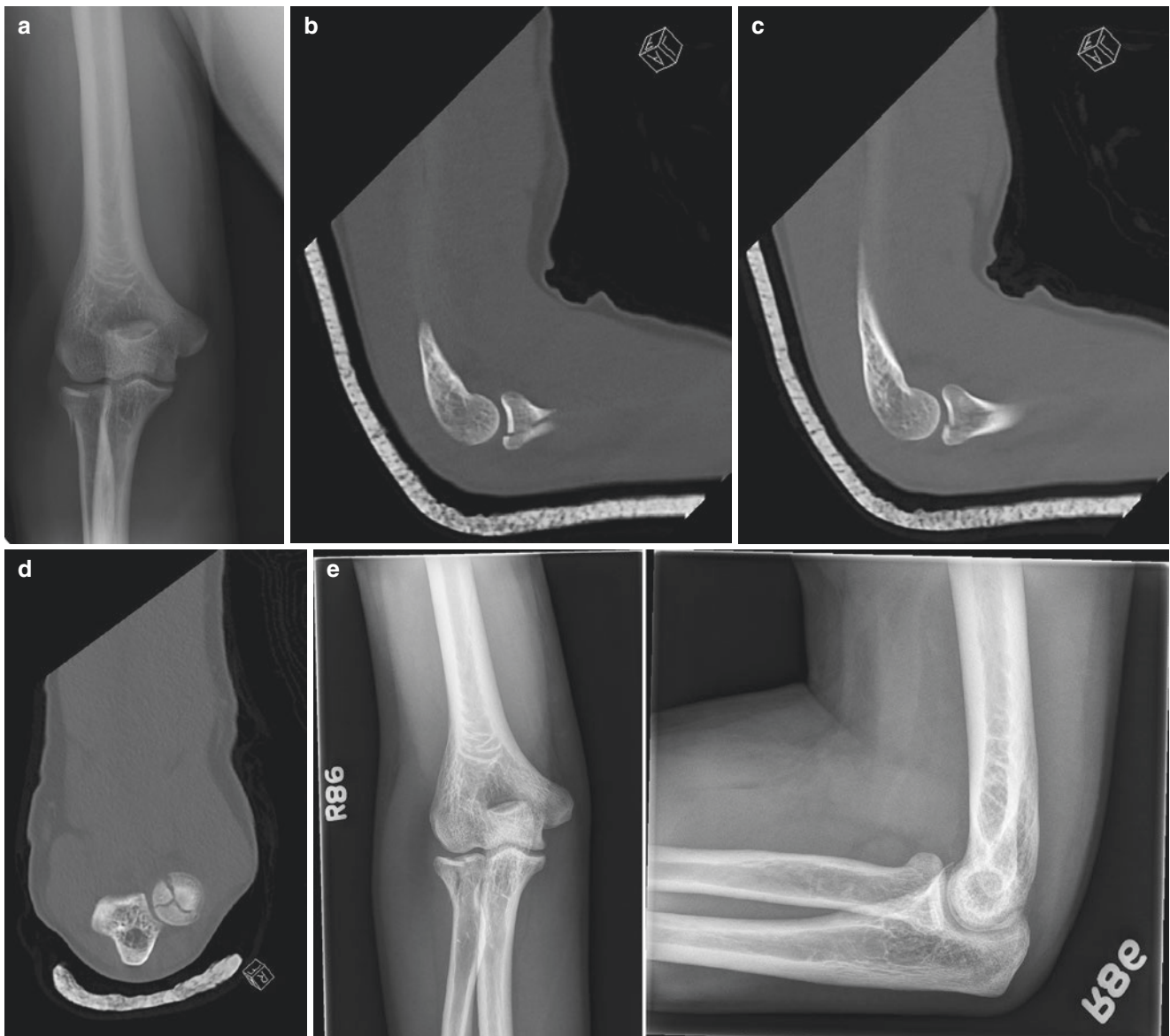
Enthusiasm exists for the surgical approach, either open reduction internal fixation (ORIF) or replacement. But let's back up for a minute. Do all radial heads need to be fixed?

No, not all radial heads need to be fixed (*see* Figs. 18.1 and 18.2).



**Fig. 18.1** (a) Initial radiographs of left elbow following referral 4 weeks from injury. (b) Final radiographs demonstrating displacement of radial head fragment. Patient had near full painless ROM





**Fig. 18.2** (a) Injury radiograph of right radial head fracture. (b) CT to evaluate step off and consideration for operative treatment. (c) CT to evaluate step off and consideration for operative treatment. (d) CT to evaluate

step off and consideration for operative treatment. (e) Non operative treatment selected. Patient had attained near full ROM

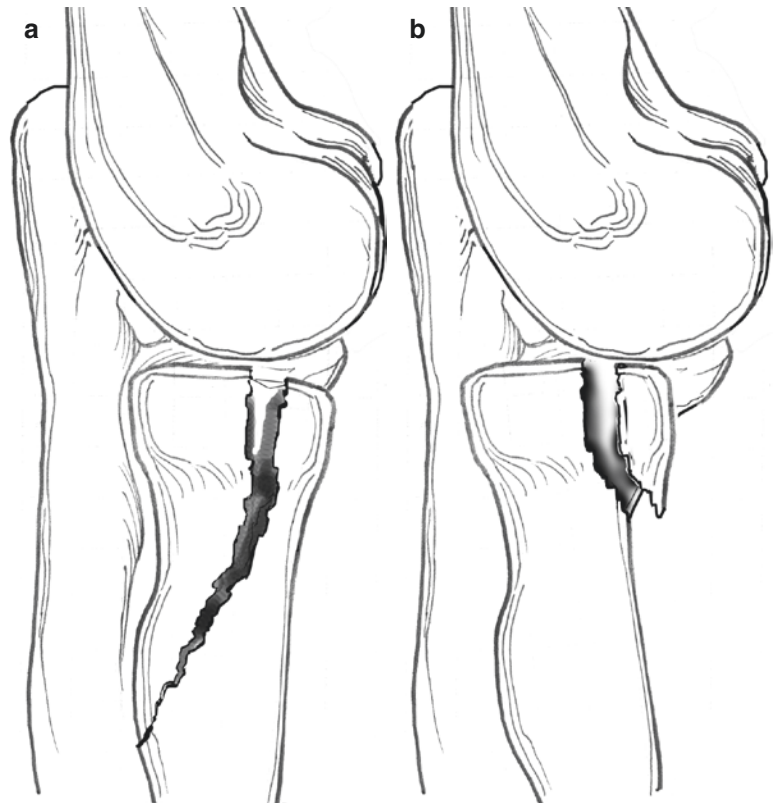
However, where do we determine the break point (no pun intended) where non-operative versus operative treatment brings about a better outcome? Let's first focus on isolated radial head fractures without associated pathology. Radial head fractures with associated pathology, including; terrible triad, head fractures, elbow dislocations and coronoid fractures; trans-olecranon fracture dislocations with radial head fractures; and longitudinal forearm injuries, such as Essex-Lopresti with radial head fractures will be discussed in other chapters.

Much of clinical focus is on the number and size of radial head fragments. But just because the number of fragments exceeds 3 will not mean that the radial head should get replaced [1]. Patient age, bone quality, physical demands, and associated medical conditions need to be considered. Also to be considered: Is the articular cartilage thickness criteria of a 2–3 mm step or separation, adequate for ORIF? Is there a block in pronation/supination, an indication for fixation?

In reference to the clinical evaluation, I have tended away from aspiration and injections for assistance in the clinical examination as intra-articular injections have been found not to be efficacious or necessary [2].

In addition to the critical concern that intra-articular step-off be greater than 2 mm when considering surgical intervention, there is also the need to consider orientation and relationship of the radial head and its fragments to the capitellum. In the case of a partial head fracture and there is a portion of the head and neck, and the constant fragment still attached to the shaft, the alignment of the head and neck to the capitellum needs to be evaluated. If the constant fragment is small and the larger fragment is still aligned with the capitellum/neck, fixation may not be required. On the other hand, a large constant fragment with subluxation may require ORIF (see Fig. 18.3).

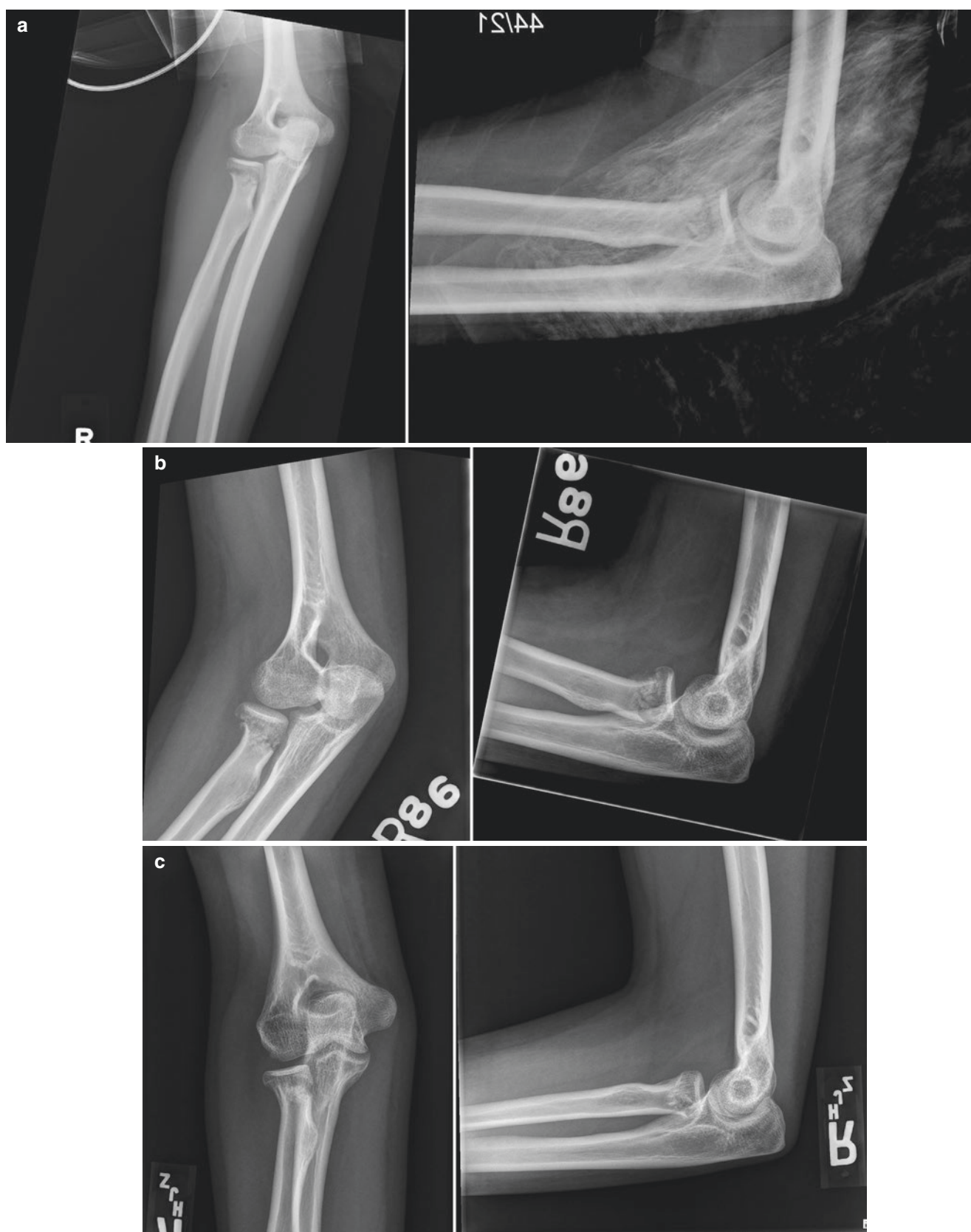
**Fig. 18.3** (a) Large fragment separate from the shaft yet not displaced relative to capitellum, thus non-operative treatment is an option. (b) Small fragment in alignment with capitellum but radial head, neck and shaft displaced thus indicating possible surgical intervention indicated



I tend not to use or focus on various classification systems, such as the Mason and the modified Mason for treatment guidelines, but more on fracture characteristics [3, 4].

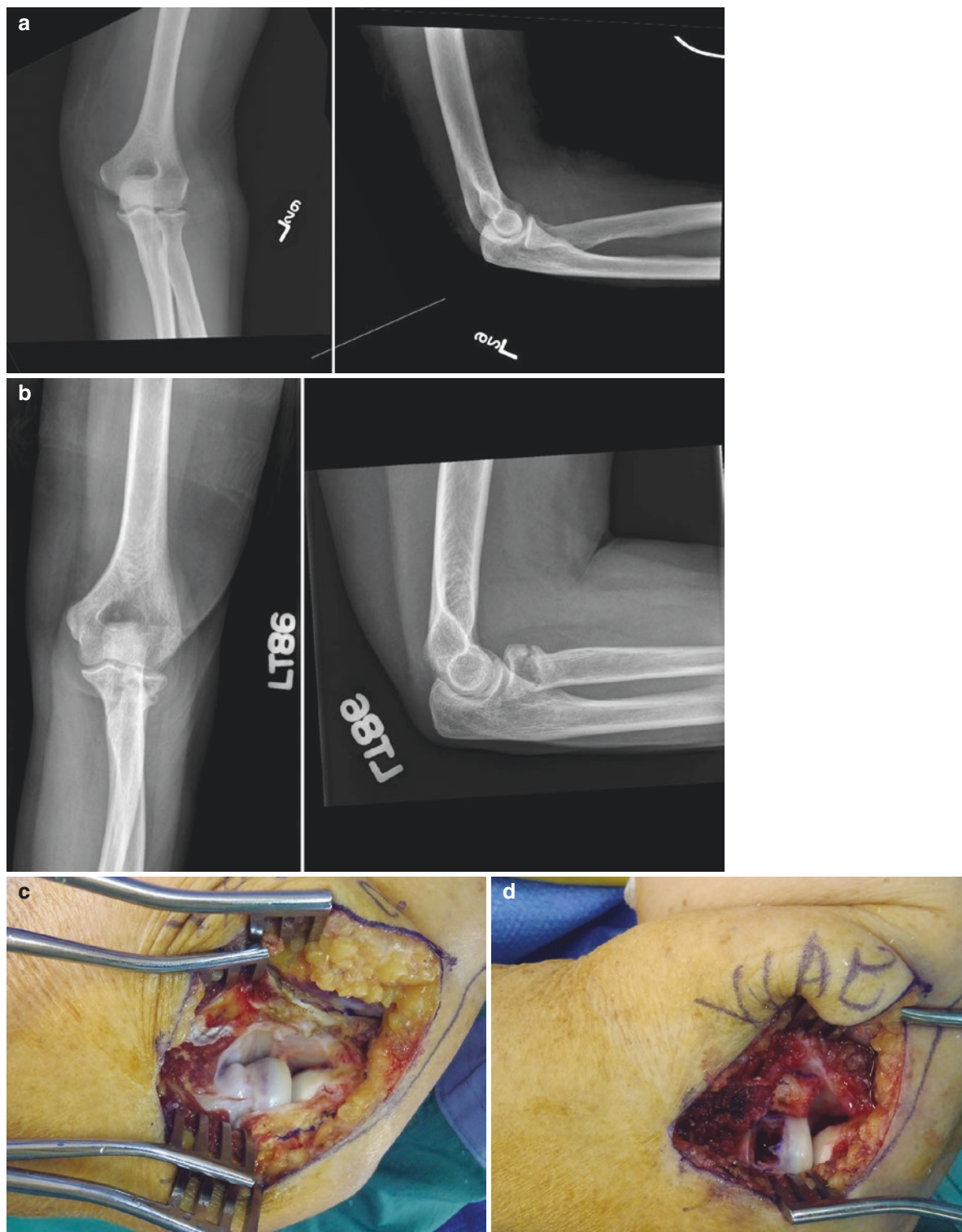
In patients with medical problems, chronic illness, or multi-system trauma, there may be a risk for delayed union or non-union despite initial minimal displacement (see Fig. 18.4a–f).





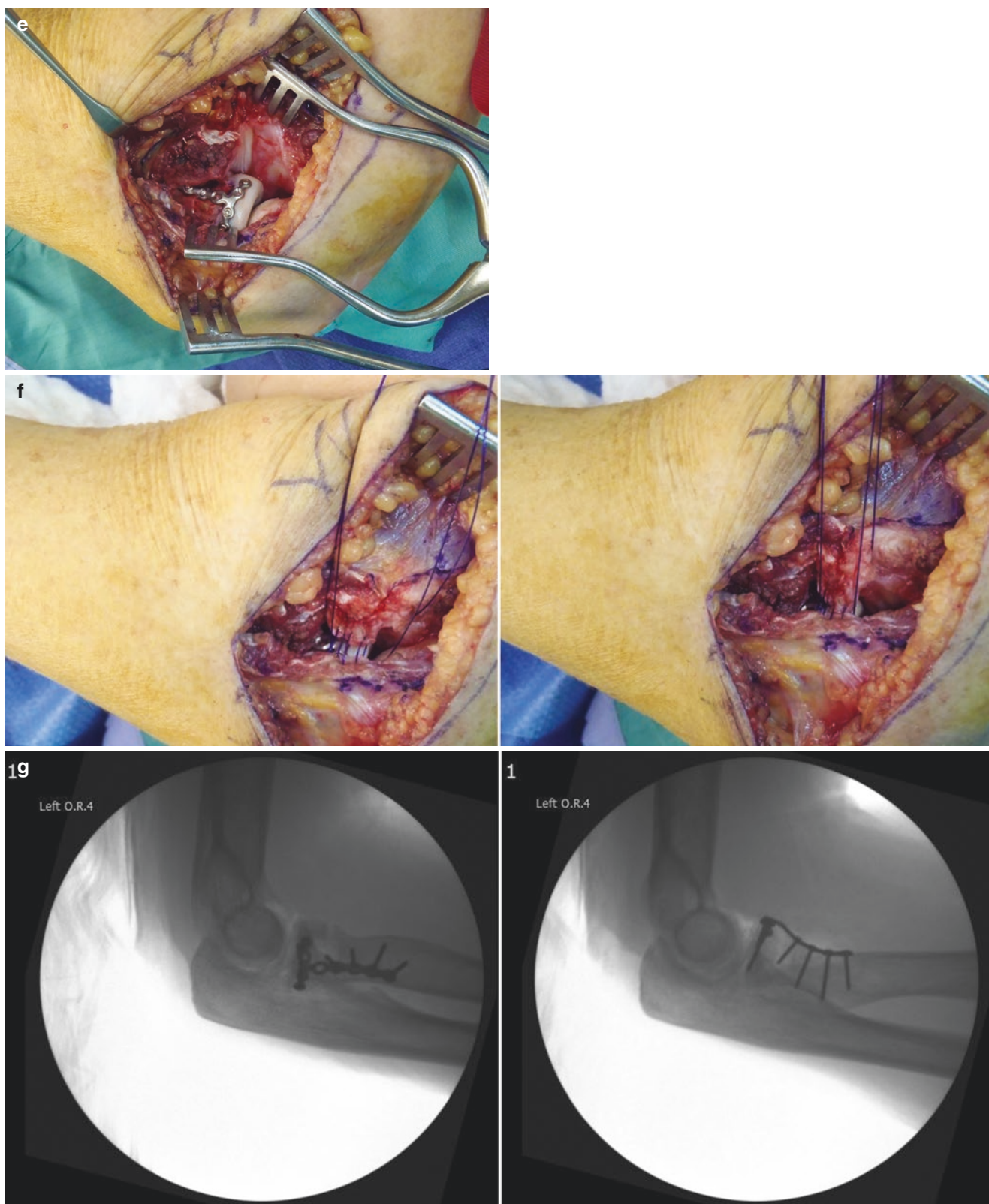
**Fig. 18.4** (a) Initial injury radiographs demonstrating left radial neck fracture. (b) 4 week follow up radiographs demonstrating resorption and concern for possible nonunion. (c) 5-month follow-up with healed neck fracture

Sometimes ORIF is indicated for non-union (*see* Figs 18.5).



**Fig. 18.5** (a) Initial injury radiographs of left radial neck fracture. (b) 5-month follow-up with painful non-union. (c) Exposure of radial neck nonunion. (d) Radial neck prepared with burr to allow insertion of unicortical corticocancellous distal radius bone graft. (e) 1.5 mm locking

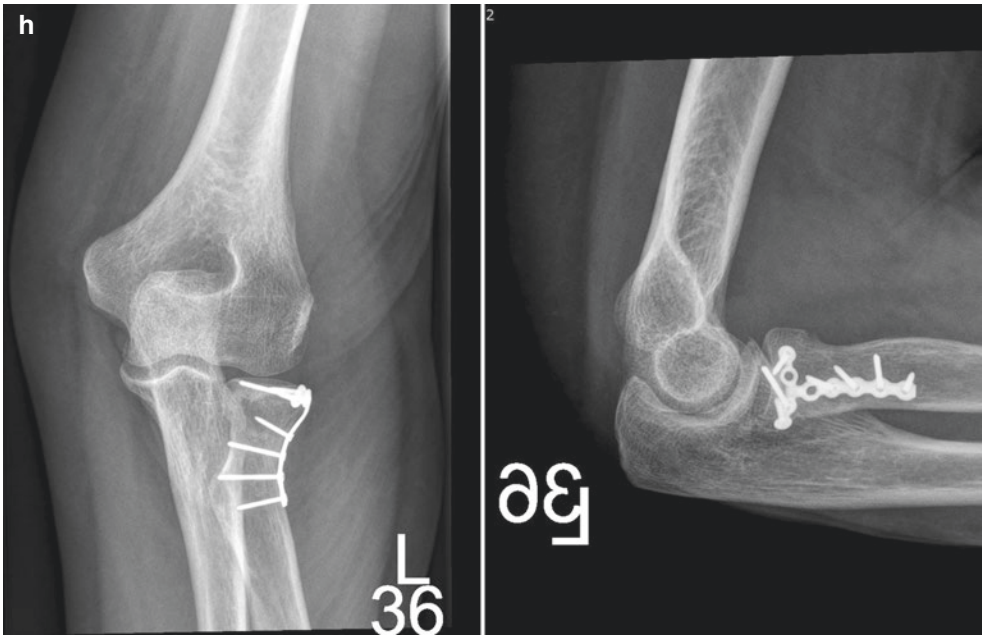
mini T-plate in safe zone. (f) 2-0 PDS placed in annular ligament then tensioned. (g) Intra-operative radiographs following bone grafting from distal radius and ORIF. (h) Healed radial neck non-union



**Fig. 18.5** (continued)



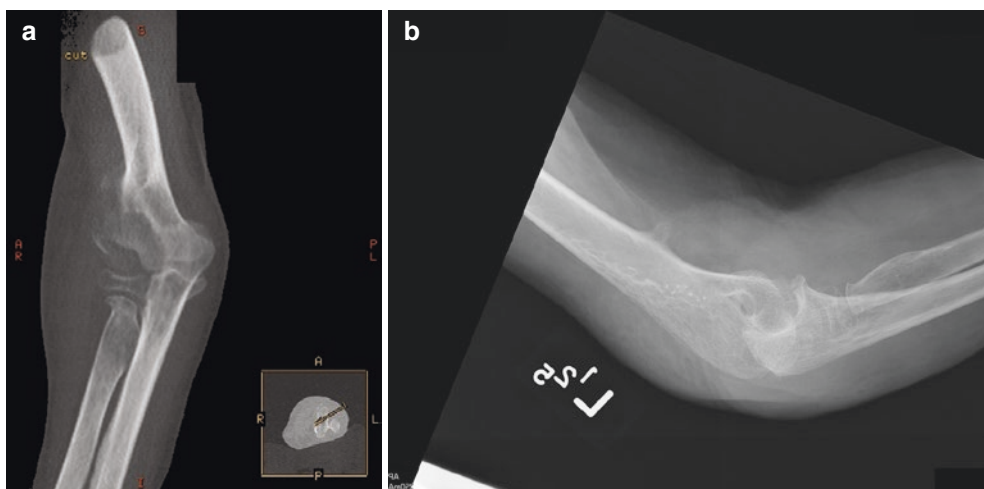
**Fig. 18.5** (continued)



Non-unions may be asymptomatic and patients may not require surgical intervention (*see* Figs. 18.6 and 18.7).



**Fig. 18.6** (a) Initial injury radiographs demonstrating left radial neck fracture. (b) Follow-up radiographs with established non-painful non-union, with no limitations on patient's function



**Fig. 18.7** (a) Radiographs from referring hospital for left elbow fracture dislocation with finding of long standing painless radial neck nonunion. (b) Radiographs from referring hospital for left elbow fracture dislocation with finding of long standing painless radial neck nonunion

If surgery is indicated, what surgical options can we offer?: we have ORIF, replacement, or excision in our armamentarium. Rarely, allograft may be considered (see Fig. 18.8a–c).



**Fig. 18.8** (a) Radiographs of left elbow demonstrating open Monteggia Bado Type II with bone loss. (b) Intraoperative radiographs demonstrating proximal radius bone defect. (c) Radiographs following revision ORIF with allograft proximal radius and head, and olecranon



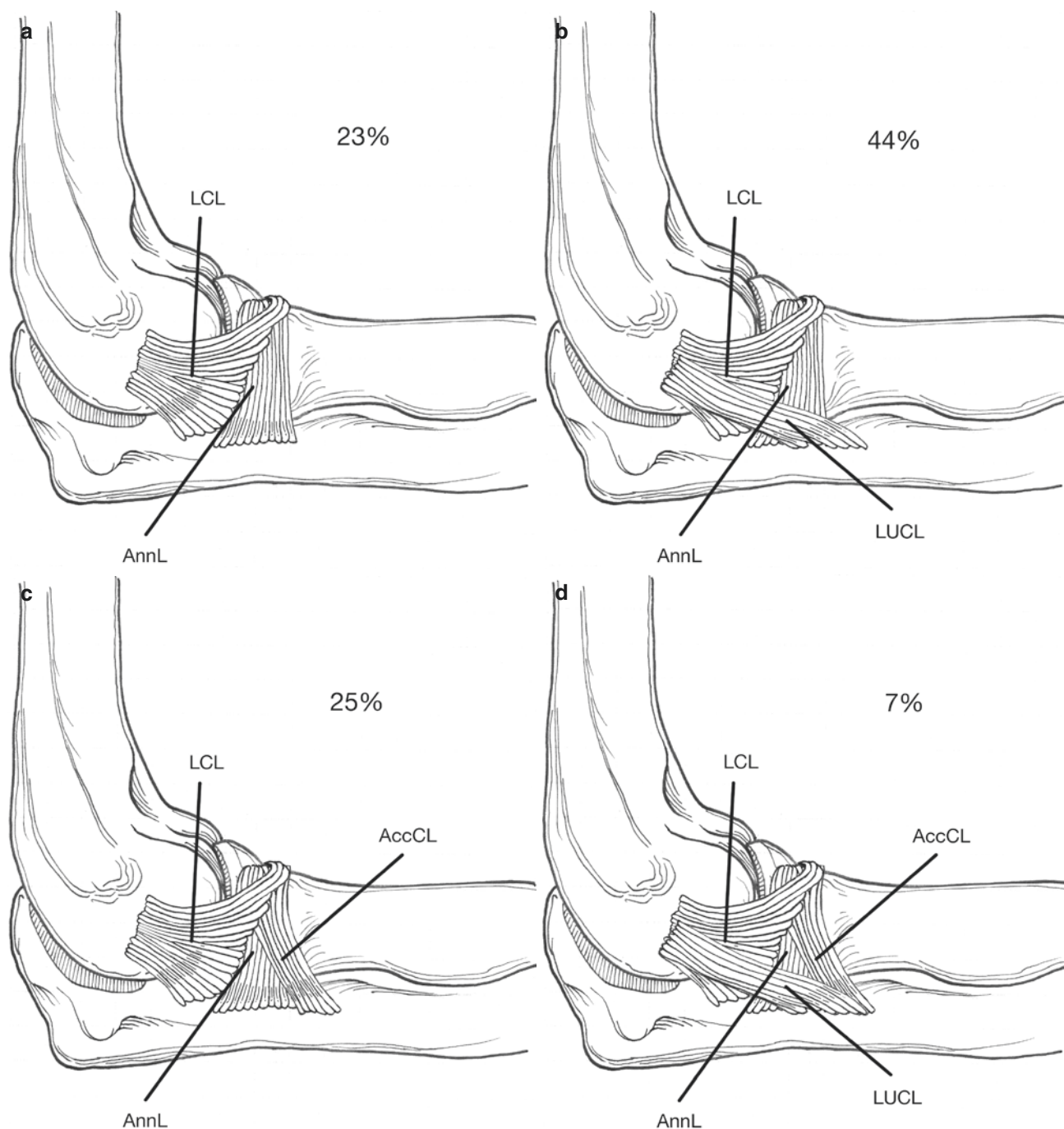


**Fig. 18.8** (continued)

(Patient positioning, prepping, and draping is presented in Chap. 15.)

If ORIF is to be performed, I prefer a lateral approach anterior to the lateral collateral ligament complex. I avoid using the term radial collateral ligament, as the complex of

lateral ligament stabilizers makes individual structures difficult to identify. Four groups of the lateral collateral ligamentous complex have been described. Various identifiable structures with group frequencies are demonstrated below (see Fig. 18.9a–d).



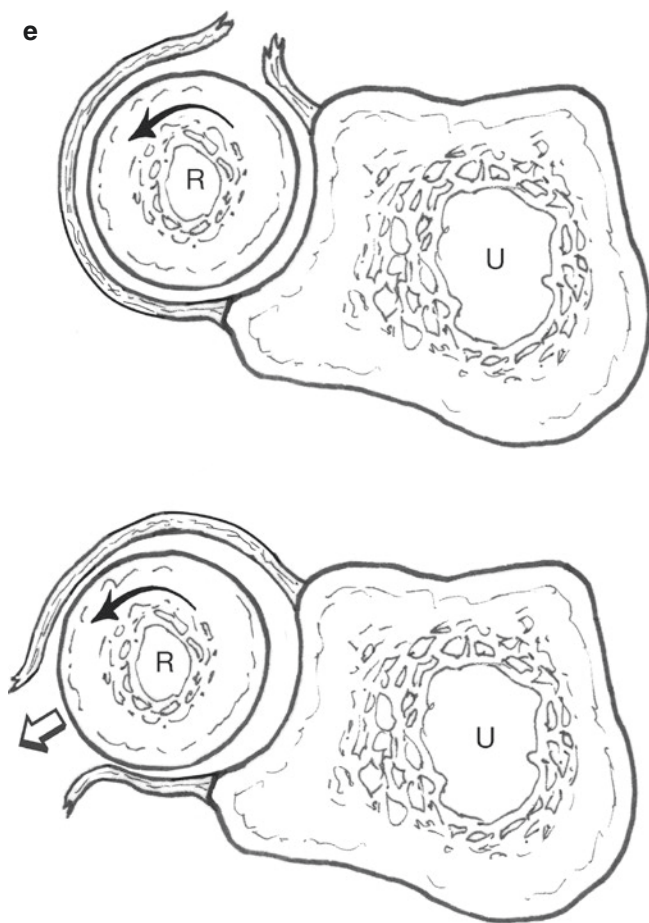
**Fig. 18.9** (a) Group 1—23%—Lateral Collateral Ligament (LCL), Annular Ligament (AnnL). (b) Group 2—44%—LCL, AnnL, Lateral Ulnar Collateral Ligament (LUCL). (c) Group 3—25%—LCL, AnnL, Accessory Collateral Ligament (AccCL). (d) Group 4—7%—LCL,

AnnL, AccCL, LUCL. (e) Radial head “escaping” during supination via posterolateral opening in annular ligament, where anterior opening may provide some restraint

I will stick with the term lateral collateral ligament complex and not use terms such as radial collateral or lateral ulnar collateral ligament as if these are easily identified or omnipresent structures.

The posterior interosseous nerve will be visualized with the lateral approach as the nerve will be closer to the area of fixation in contradistinction to a posterolateral approach where the nerve crosses more distal. I prefer the lateral approach anterior to the lateral collateral ligamentous com-

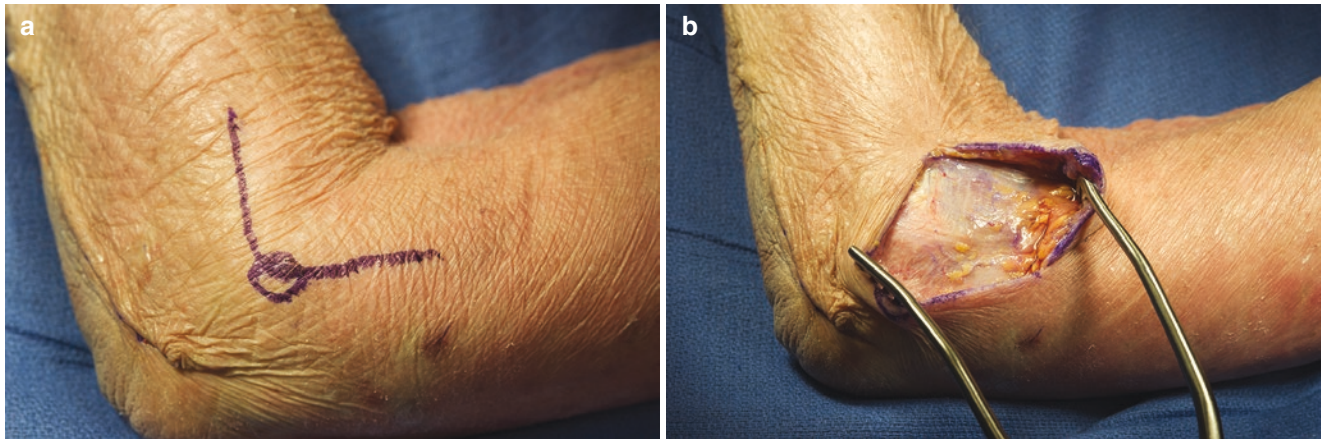
plex as opposed to any of the other lateral or posterolateral approaches, because it keeps the ligamentous complex intact, exclusive of the annular ligament. The radial head fracture especially if it is a partial head fracture, tends to be more of an anterior fragment which is better accessed via the anterior approach via a lateral incision. Also by dividing the annular ligament anterior, the head is supported and may have less tendency to “escape” laterally (*see* Fig. 18.9e).



**Fig. 18.9** (continued)



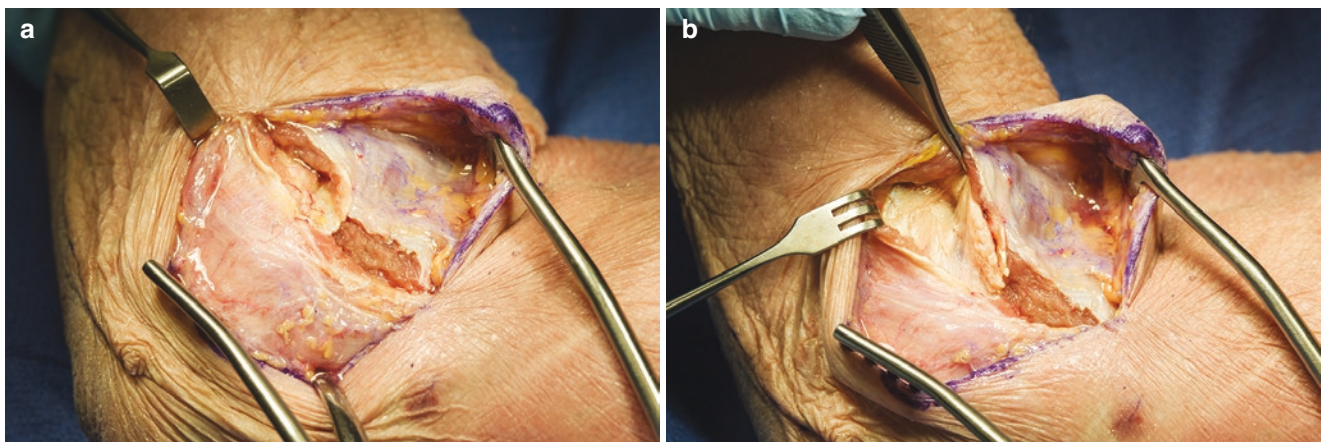
The skin incision is along the supracondylar ridge and anterior aspect of the lateral collateral ligament complex (*see* Fig. 18.10).



**Fig. 18.10** (a) Skin incision outlined centered over lateral epicondyle; circle. (b) Skin flaps elevated

The posterior radial collateral vessels will occasionally need to be cauterized. The wrist extensors are elevated anterior to the capitellum and the lateral collateral ligamentous complex. The hemarthrosis will be evacuated after the capsule is opened.

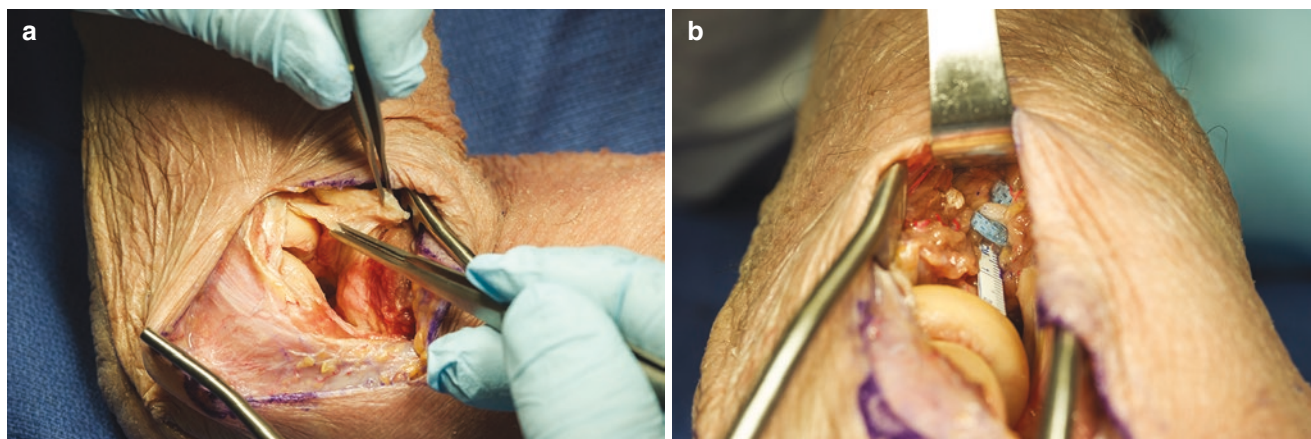
The incision is carried distal, down to the annular ligament. The interval or planes at the elbow are difficult to develop because, essentially, the elbow interval is all muscle. The muscle is split in line with the incision and the deep fascia of the extensor carpi radialis brevis (ECRB) is encountered. When the fascia is split, the fascia of the supinator is visualized (*see* Fig. 18.11).



**Fig. 18.11** (a) Fascia incised along supracondylar ridge then along anterior aspect of lateral collateral complex. (b) Deep fascia of extensor carpi radialis brevis incised exposing supinator

If I am projecting plate fixation, I will dissect the supinator to identify the posterior interosseous nerve. Despite the numbers frequently espoused as 4 cm distal to the radio-capitellar joint for the posterior interosseous nerve

(PIN) location, I have been taken with a very close proximity of the PIN to the neck, regardless of the forearm position [5, 6] (*see* Fig. 18.12).



**Fig. 18.12** (a) Annular ligament incised in pick ups. (b) Posterior interosseous nerve dissected with blue background deep to nerve

Great care is paid to prevention of synovial reflections stripping from the fragments.

Fixation type is driven by the patient's age, needs, quality of bone, and associated injuries, I have not offered a particular number of fragments used for fixation criteria, but I will say that in the young healthy person, it is not uncommon to piece together a 5–6 fragment head. The safe zone for plate placement also needs to be appreciated, following roughly the interval between the radial styloid and the Lister's tubercle [7]. This area of thinned cartilage along the lateral aspect of the head can be seen and used as a guide for plate positioning.

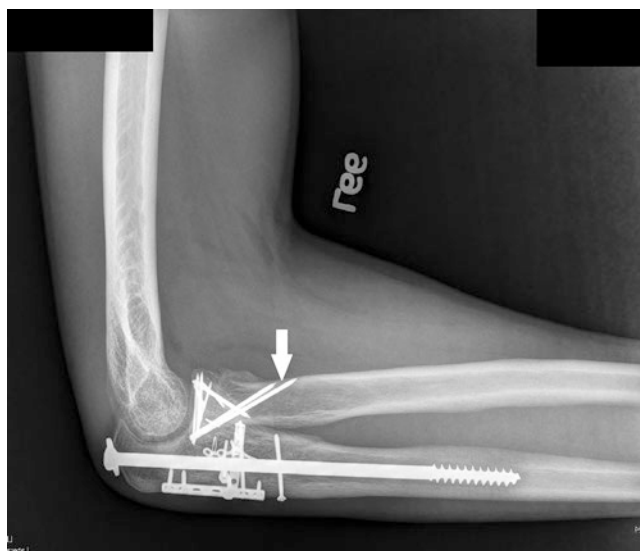
A key somewhere between the head and neck is usual. Neck fractures frequently have a metaphyseal projection or spike that will facilitate the alignment and reduction. Head fragment stabilization is usually with 0.035- or 0.045-in. K-wires, which may be smooth but may migrate if not buried or incarcerated. Threaded K-wires, which may be recessed with a burr or 1.5 mm headless screws, may also be used. To stabilize the head to the neck I occasionally use what I call a tripod technique. Oblique K-wires are inserted in a fashion as such that they engage the opposite cortex and occasionally obviate the need for plate fixation (*see* Figs. 18.13, 18.14 and 18.15).



**Fig. 18.13** Injury radiographs of left elbow transolecranon fracture dislocation. Radial head fracture fixation utilized for demonstration purposes of tripod technique



**Fig. 18.14** AP Follow up radiograph demonstrating fixation with three oblique K wires (*arrow*) in concert with K wires and headless 1.5 mm screws



**Fig. 18.15** Lateral Follow up radiograph demonstrating fixation with three oblique K wires (*arrow*) in concert with K wires and headless 1.5 mm screw

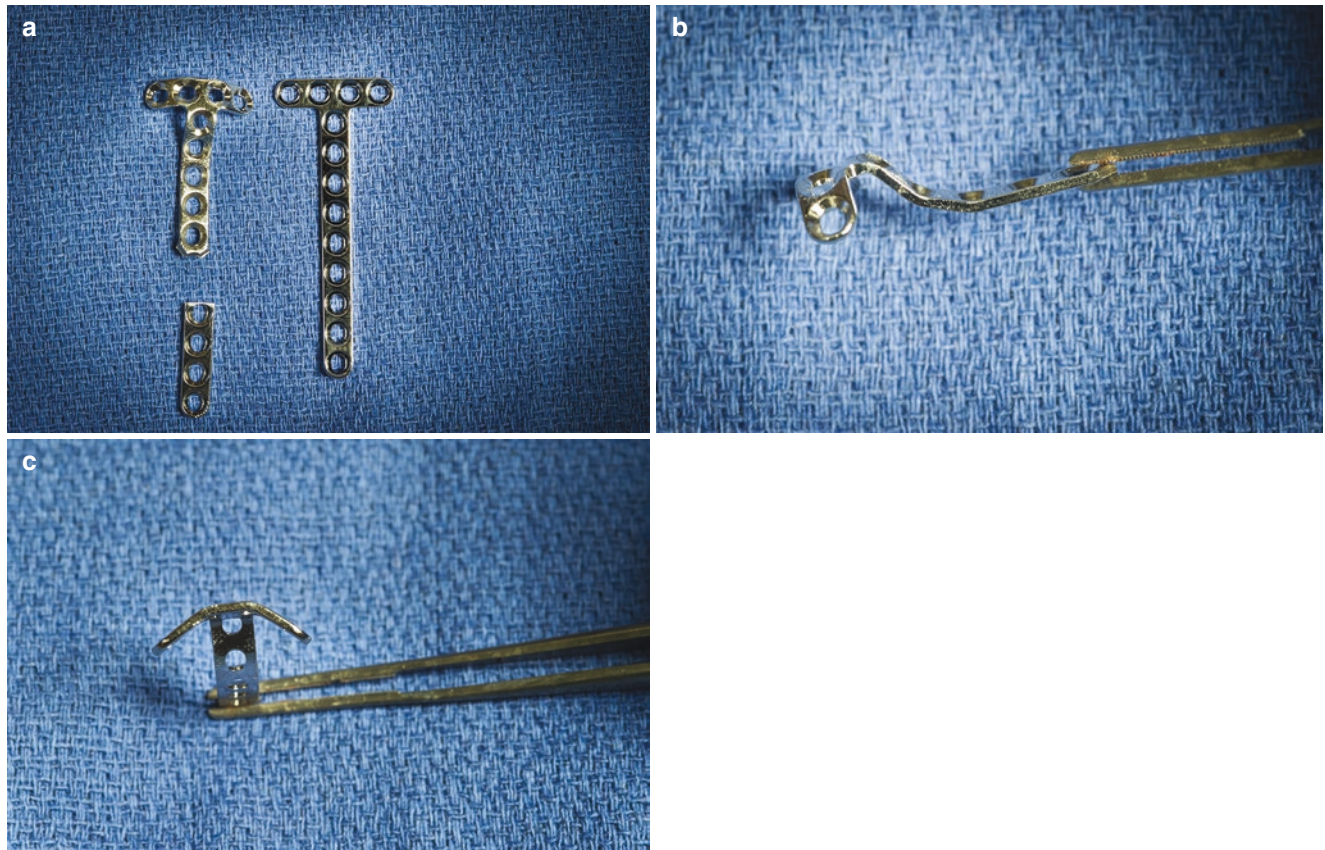
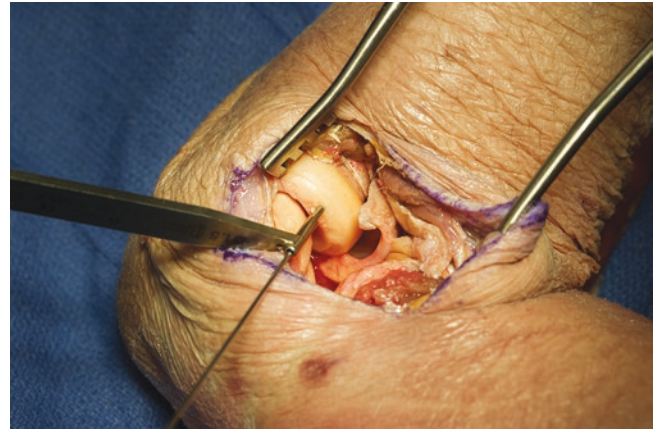


ORIF can be performed with headless screws, buried mini-fragment screws, or buried smooth or threaded K-wires, and a combination of other screws, plates, and oblique buried K-wires.

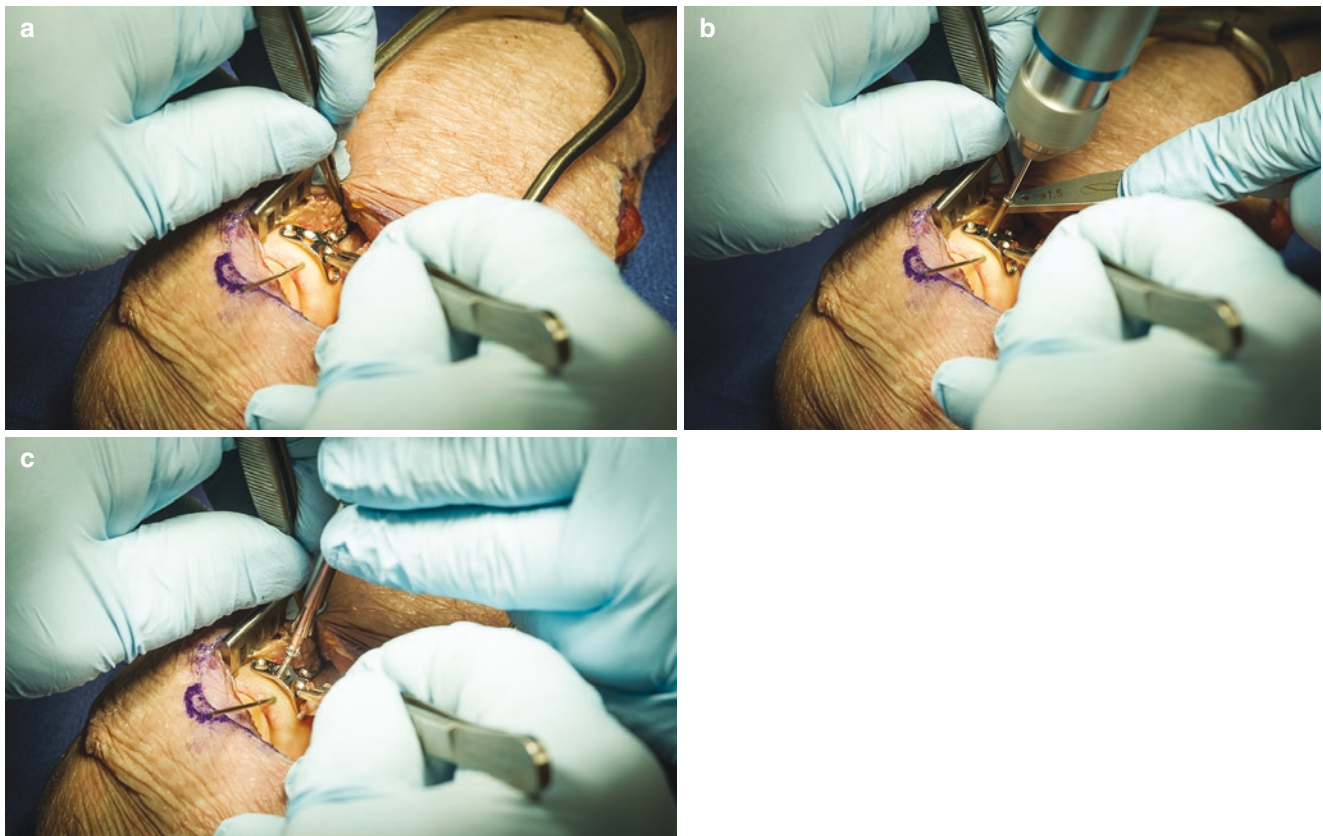
I do not use pre-contoured radial head plates, as I prefer the 1.5 mm or 2.0 mm locking mini-plate systems. A non-

locking, as opposed to locking, 2.0 mm fragment T-plate is used for demonstration due to supply issue for the dissections (*see* Figs. 18.16, 18.17, 18.18, 18.19, 18.20, 18.21, 18.22, 18.23, and 18.24).

**Fig. 18.16** Fracture reduced and provisionally stabilized with K wire



**Fig. 18.17** (a) 2.0 mm non locking T plate cut and contoured. (b) 2.0 mm non locking T plate cut and contoured. (c) 2.0 mm non locking T plate cut and contoured



**Fig. 18.18** (a) Open reduction and internal fixation with plate. (b) Open reduction and internal fixation with plate. (c) Open reduction and internal fixation with plate

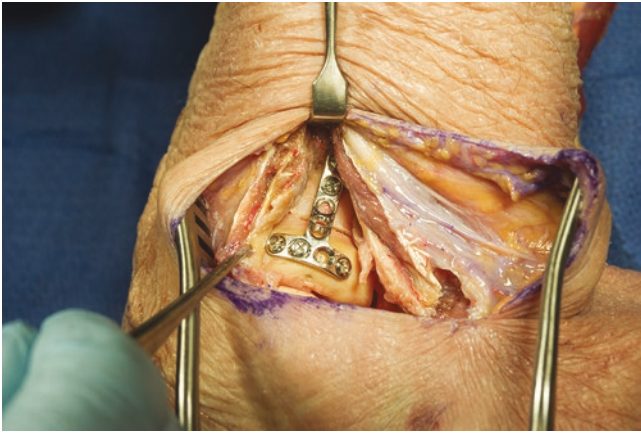


**Fig. 18.19** Plate secured to head



**Fig. 18.20** Fixation down shaft

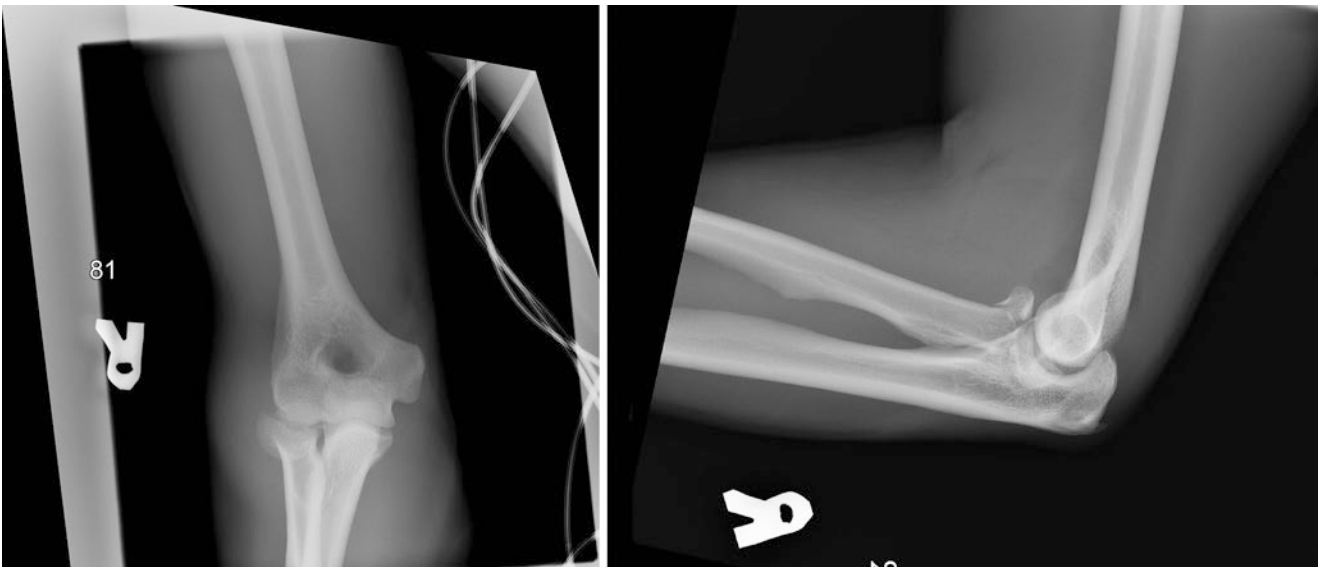




**Fig. 18.21** Final fixation. Note the narrowing of the articular cartilage where T position is seating reflecting limited potential contact area of head on pronation and supination



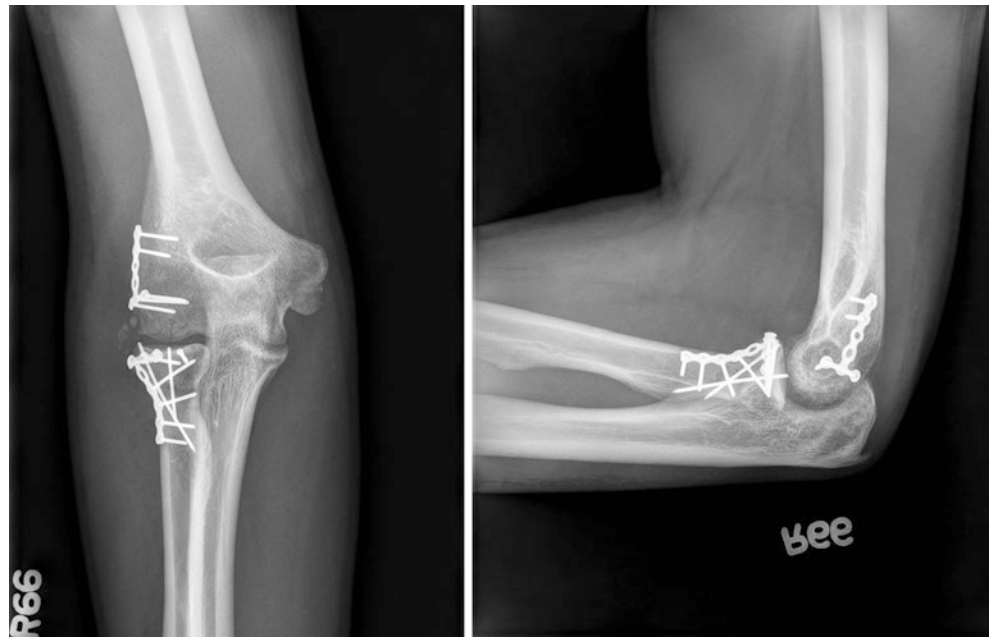
**Fig. 18.22** Positioning of the plate relative to Lister's tubercle and radial styloid K wires



**Fig. 18.23** Injury radiographs of right elbow demonstrating isolated radial head fracture

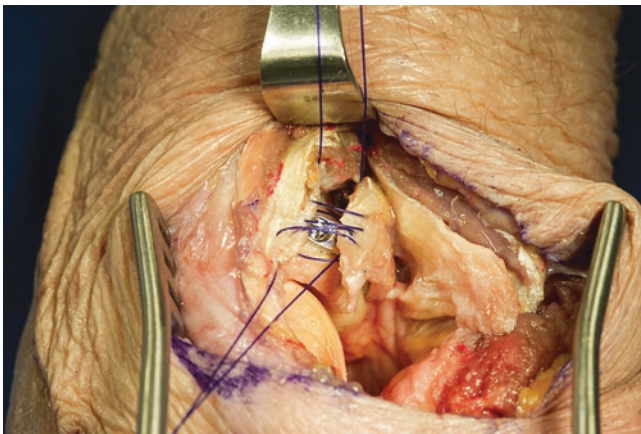


**Fig. 18.24** Radiographs following open reduction internal fixation via epicondyle osteotomy. Fixation performed with two oblique tripod K wires, headless screws and 1.5 mm mini-fragment locking plate

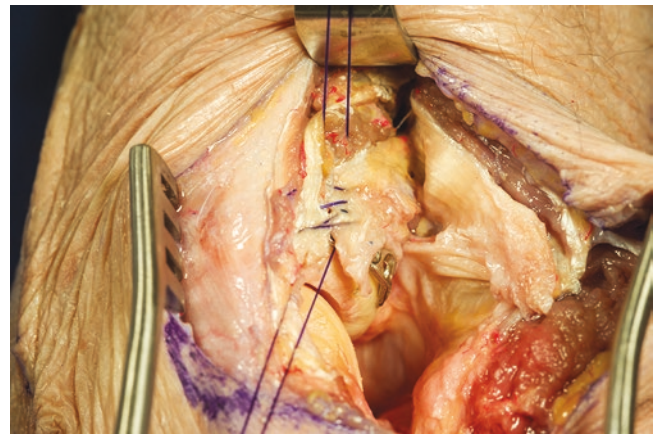


I also liberally use bone graft, with allograft or autograft to prevent collapse. Frequently there is a window or comminuted defect to insert the graft. If not, I will take a burr to create a window to fill in the metaphyseal defect beneath the radial head articular surface, similar to the case demonstrated

in Fig. 18.5a–e. Closure is performed with repair of the annular ligament using buried 2.0 PDS sutures. The two sutures are pre-placed prior to final tying. If only one suture is placed and tied, it is more difficult to place the second suture (*see* Figs. 18.25 and 18.26).



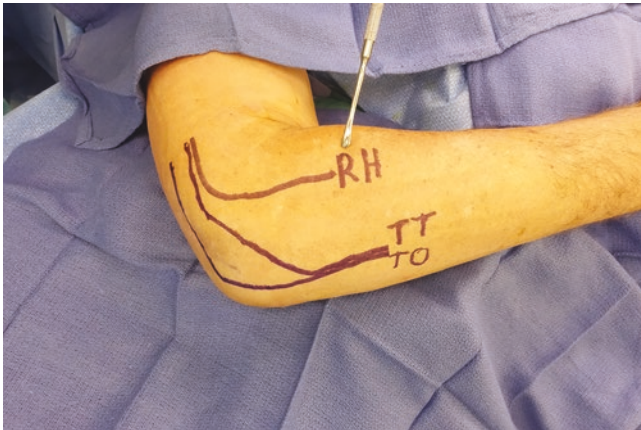
**Fig. 18.25** Annular ligament sutures positioned for repair



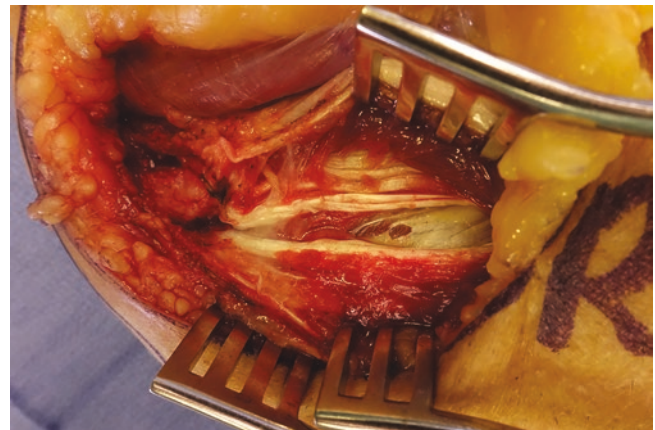
**Fig. 18.26** Sutures tensioned

The remaining fascial approximation is completed with closed buried 2.0 PDS sutures (*see* Figs. 18.27, 18.28, 18.29, 18.30, 18.31, 18.32, and 18.33).

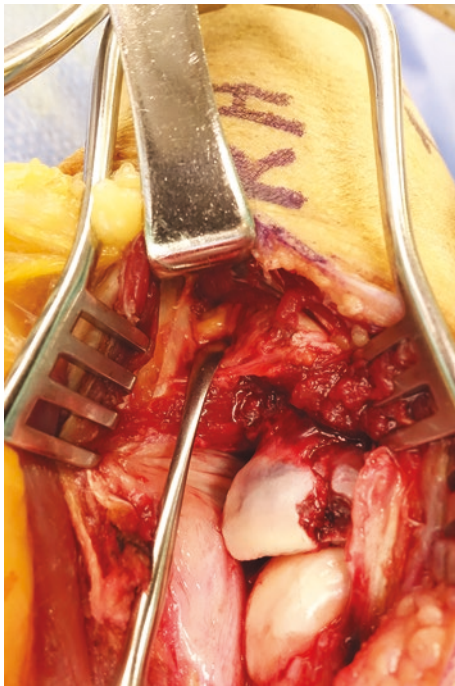
**Fig. 18.27** Injury radiographs of right radial head and neck fracture with instability on clinical examination



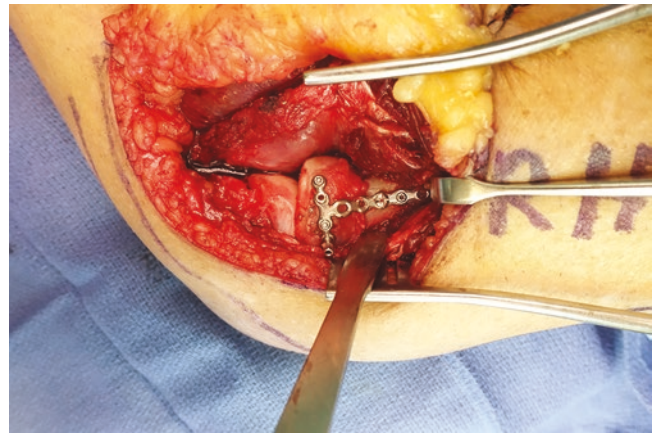
**Fig. 18.28** Approach outlined for right radial head fracture with comparison to the other lateral elbow approaches terrible triad (TT), transolecranon (TO)



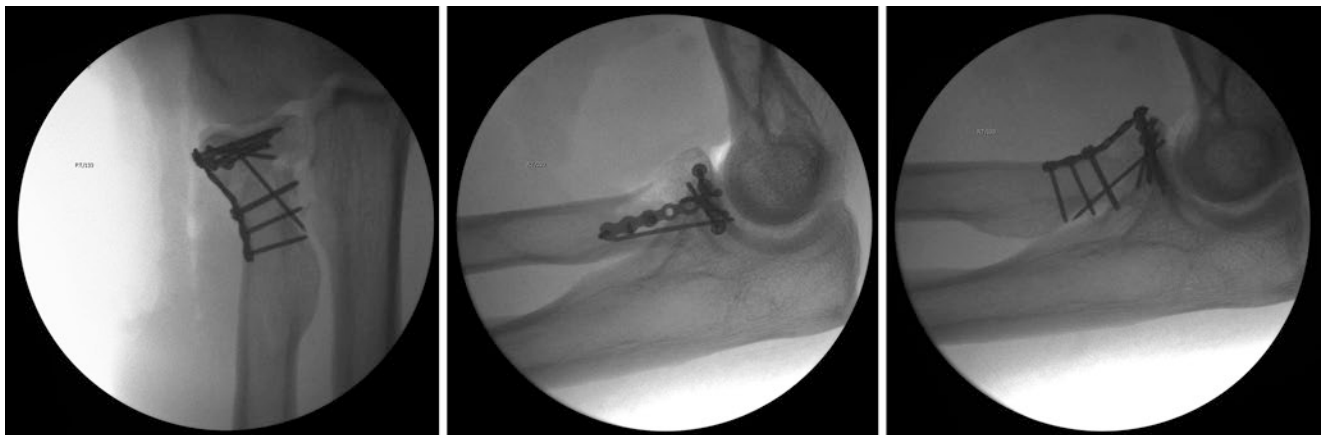
**Fig. 18.29** Extensor carpi radialis brevis deep fascia split exposing supinator



**Fig. 18.30** Radial head fracture exposed and posterior interosseous nerve exposed at end of Freer



**Fig. 18.31** Fixation of right radial head with 1.5 mm locking plate with headless screws placed prior to plate fixation. Note use of 2.0 mm screw to improve purchase after 1.5 mm screw cut out



**Fig. 18.32** Intraoperative C arm radiographs following open reduction internal fixation



**Fig. 18.33** Intraoperative radiograph following open reduction internal fixation. No hardware penetration in joint on direct visualization



## 18.2 Patient Rehabilitation

Range of motion exercises usually begin on the first postoperative visit, with the timing of splinting and therapy predicated on the quality of bone fixation. Dynamic splinting may be performed at 6–8 weeks. Strengthening is usually started at 6–8 weeks, but no weight-bearing for 3 months. I counsel the patient on the potential for elbow flexion contractures and the need for subsequent capsulectomies.

## 18.3 Replacement Arthroplasty

Replacement arthroplasty must be considered, but is rarely used in my younger patients. The replacement option is usually invoked when there is poor quality bone and extensive comminution precluding ORIF. Cited number of fragments is usually greater than 3, which can make ORIF difficult to perform [1].

Replacement is not necessarily a panacea or the single answer to radial head problems. Simplistically speaking, the radial head is not circular; it tends to be elliptical, with the head offset from the neck, making prosthetic design and development difficult for replacement of the native head [8]. The greatest dimension is perpendicular to the proximal radial notch, with the forearm in neutral rotation. Clinical studies have demonstrated significant revisions were required following replacements in a number of scenarios [9, 10]. When I perform replacements I favor the bipolar head, acknowledging the work demonstrating better radiocapitellar stability with a monoblock, monopolar design [11, 12]. I like the way the bipolar head self orients to the capitellum which I believe decreases capitellum cartilage wear. There are other biomechanical studies that report similar results with either monoblock or bipolar implants in restoring elbow stability (see Figs. 18.34, 18.35, 18.36, 18.37, 18.38, 18.39, 18.40, and 18.41) [13, 14].



**Fig. 18.34** Injury radiographs of isolated left radial head fracture

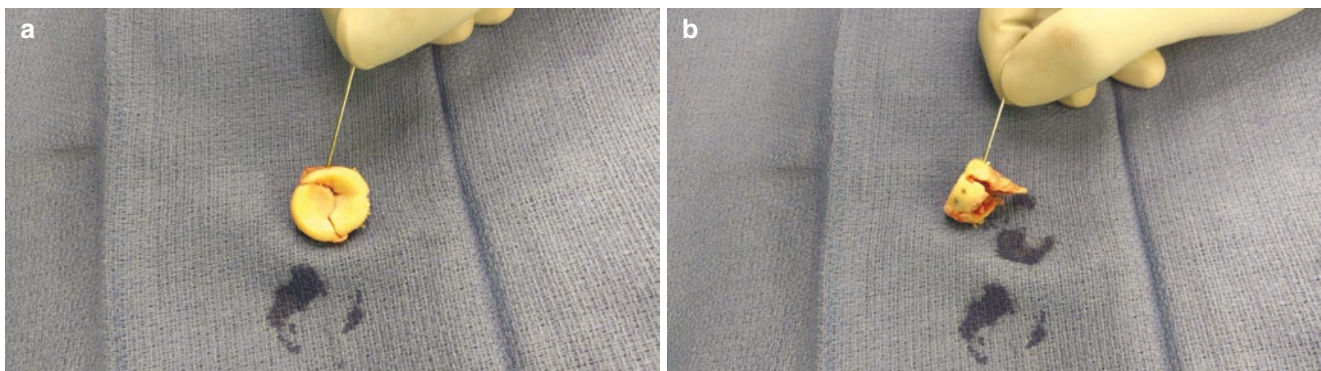
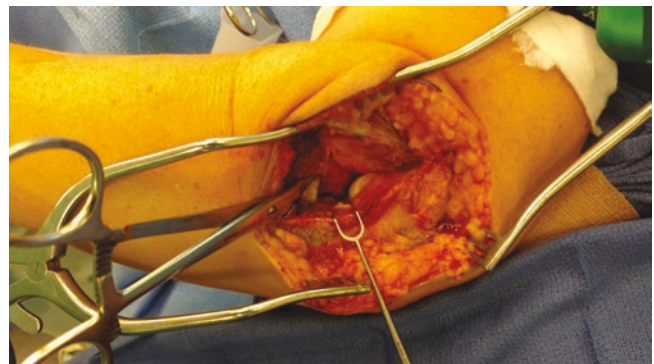


**Fig. 18.35** Radiographs following replacement arthroplasty with bipolar head. Note slight increase in lateral ulnohumeral joint space relative to the medial joint space



**Fig. 18.36** Injury radiographs of isolated left radial head fracture

**Fig. 18.37** Lateral approach following radial head excision

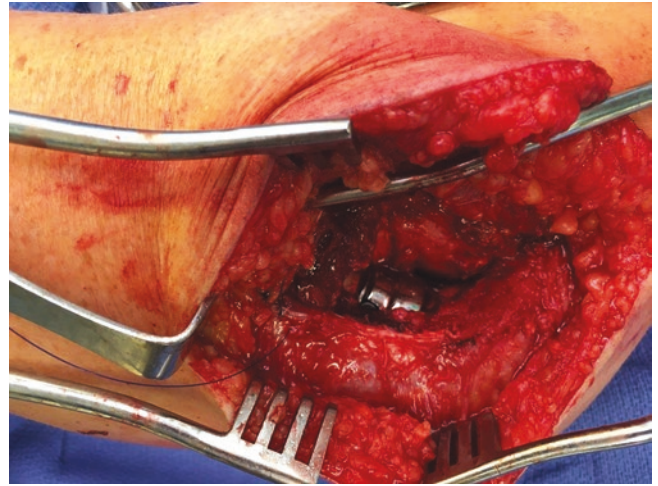


**Fig. 18.38** (a) Radial head reconstructed on back table for sizing. (b) Radial head reconstructed on back table for sizing

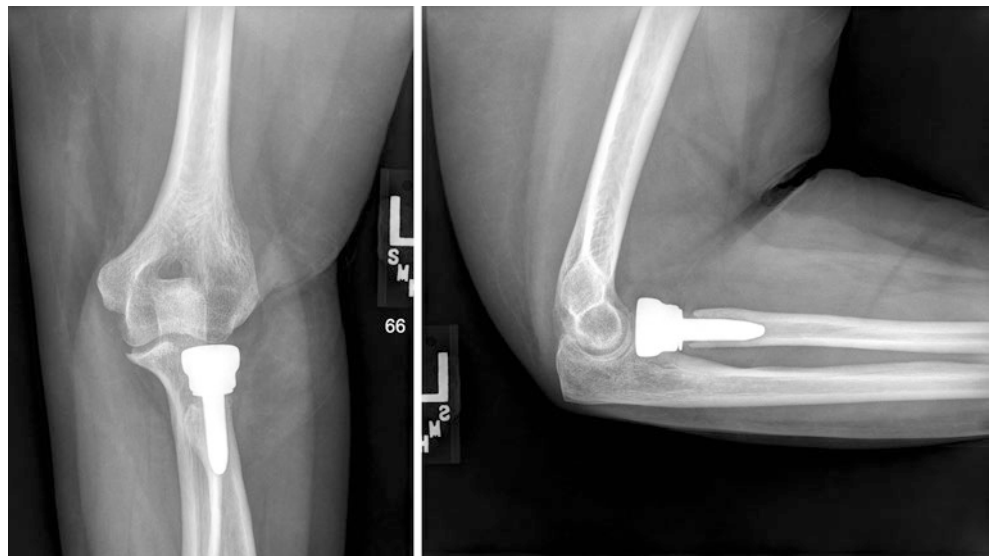




**Fig. 18.39** Monoblock implant assembled



**Fig. 18.40** Implant seated and radial head reduced



**Fig. 18.41** Radiographs following replacement arthroplasty with monoblock system. Case courtesy of Dr. Raymond Pensy MD

## 18.4 Radial Head Excision

Radial head excision can be supported by reports of good clinical outcome despite development of radiographic arthritis [15–19]. However, I have been very disenchanted with radial excision, having been referred patients and having seen patients with continued elbow pain following excision.

Radial head fracture may be a component of an unappreciated associated injury complex, terrible triad, trans-olecranon fracture dislocation, or Essex-Lopresti injuries, with excision leading to instability or recurrent dislocation. The longitudinal forearm injuries can be unmasked with an almost unanswerable problem of shortening with distal radio-ulnar complications, such as impingement following head excision. A radiographic ulnar variance finding of greater than 3 mm proximal radius excursion on a pull test (i.e., 3 mm ulnar

positive variance) occurred after radial head excision and interosseous membrane (IOM) division [20]. The same result did not occur with triangular fibrocartilage complex (TFCC) division alone. When both structures were divided greater than 6 mm of migration proximally of the radius occurred when loaded. The study reflects the importance of the IOM in the Essex-Lopresti injury. Performing a radial head excision in the scenario of a positive pull test should probably be avoided. I'm sure there are patients who have had radial head excisions that are very functional and, given that my impression may be biased, as patients who are referred to me after excision come to me because of their pain. Since I can't predict who will or will not be satisfied with radial head excision, I very rarely perform this. One patient with radial head excision is presented below following excision for chronic elbow pain; I don't have examples of acute excision (Figs. 18.42, 18.43, 18.44, and 18.45).



**Fig. 18.42** Referral radiographs of right elbow following distal humerus ORIF lateral hardware removal with persistent radiocapitellar pain



**Fig. 18.43** CT scan demonstrating radiocapitellar arthritis



**Fig. 18.44** Intra-operative radiographs following radial head excision



**Fig. 18.45** 7-month follow-up radiographs



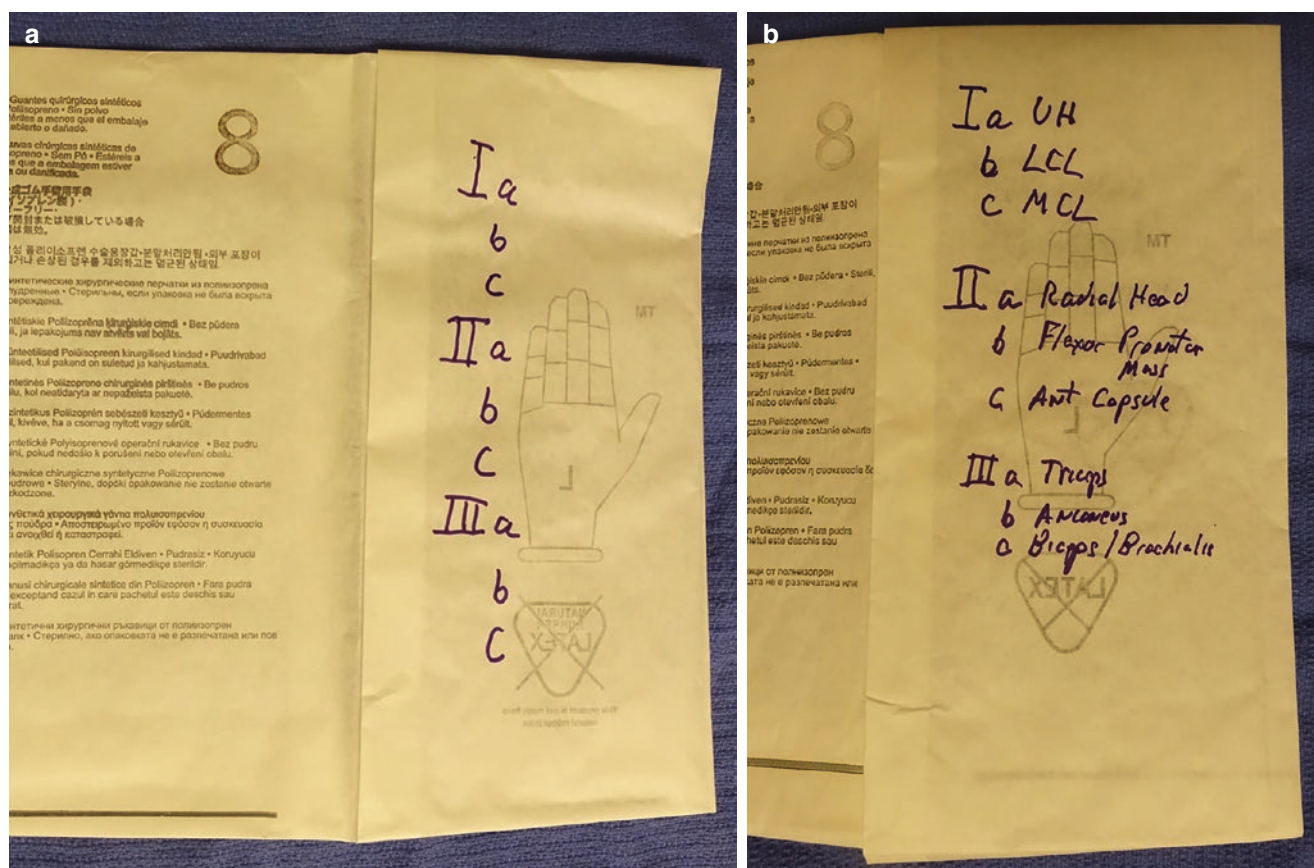
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## 19.1 Principles of Elbow Stabilization

The term *terrible triad* describes an elbow injury comprising an elbow dislocation with associated coronoid fracture and radial head fracture. Prior to the discussion of any form of

intervention, a review of the stabilizing components of the elbow will help in the understanding of the sequence of fixation. Those who have been subjected to a terrible triad patient experience with me may recognize the glove package elbow stability summary quiz (Fig. 19.1).



**Fig. 19.1** (a) Skeleton outline of elbow stability. (b) Filled-out stability outline

There are effectively three tiers of elbow stability, each with three subsets [1–4]:

- Tier 1
  - Ulnohumeral joint
  - Lateral collateral ligamentous complex
  - Medial collateral ligament
- Tier 2
  - Radial head
  - Flexor pronator mass
  - Anterior capsule
- Tier 3
  - Biceps/brachialis
  - Triceps
  - Anconeus

The first and most important elbow stability concern is ulnohumeral articulation. Joint contact is paramount for the inherent stability of any joint, but no more so than for the elbow joint. To a large extent, the elbow is stabilized by the containment of the olecranon and coronoid processes bracketing the trochlea and preventing anterior and posterior translational shearing. The coronoid is particularly critical in this respect, so fracture stabilization is key with coronoid fractures, especially those involving the base. Following the bony architecture in importance are the lateral collateral and medial collateral ligaments. The lateral collateral ligament or lateral collateral ligamentous complex is usually repaired through drill holes or suture anchors. The medial collateral ligament is only occasionally repaired, commonly in association with an open injury. I am going to avoid saying *lateral ulnar collateral ligament*, as if it is always present and the primary lateral stabilizer of the elbow. The difficulty in specifically identifying the various components of the confluence of ligaments laterally has been borne out by studies that demonstrate the presence of a lateral ulnar collateral ligament in only about 50% of cases [5]. Therefore, the overall understanding that there is a lateral restraining complex is important and needs to be addressed appropriately.

In the second tier of elbow stabilizers, the radial head has importance as a valgus stabilizer, but its importance is not as great as that of the medial collateral ligament. It is difficult to define the relative percentages of how much the radial head and medial collateral ligament impart to elbow valgus stability because their contributions change during flexion and extension, particularly for the medial collateral ligament. There is also controversy about the importance of the anterior capsule and, parenthetically, the small coronoid avulsion. I believe the anterior capsule is important because, as it avulses or tears, it comes off as a sleeve that includes at least some portion of the medial collateral ligament, thus having an impact on the soft tissue realignment of the medial collateral complex. Finally, there are dynamic stabilizers of the elbow for the biceps, triceps, brachialis, and anconeus.

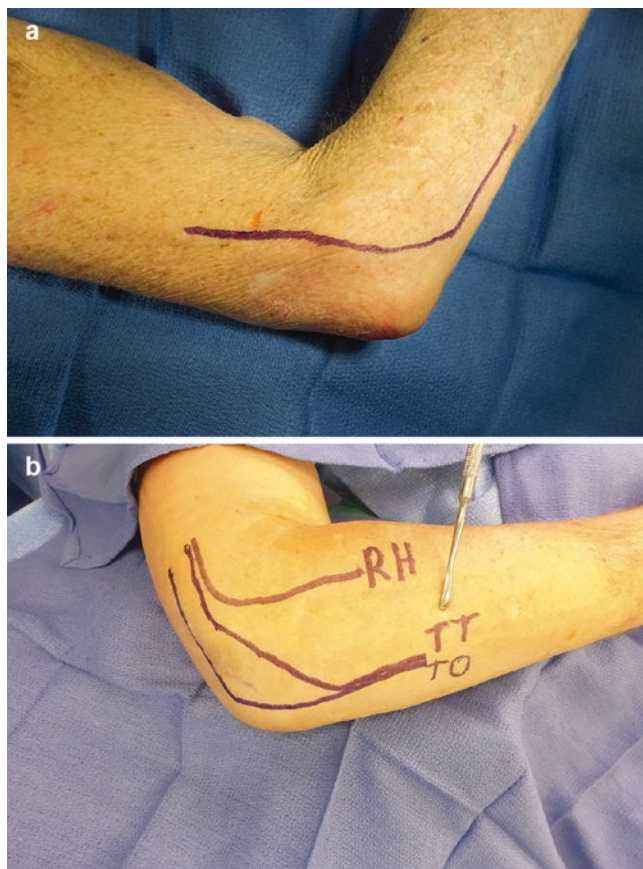
## 19.2 Surgical Techniques

The mantra chanted in the scenario of a terrible triad injury or a transolecranon fracture dislocation is that the reconstruction of the elbow must begin in its center. If you do not address the ulnohumeral joint first, you are doomed to have problems. Trying to address first the more external issues, such as ligaments or the radial head, will produce problems in gaining access to the internal structures for repair and thus in maintaining stability and concentric reduction.

Patient set-up, prepping, and draping is supine with a sterile tourniquet. The arm is on a hand table, positioned so that the elbow is at the center of the table, as demonstrated in Chap. 15.

### 19.2.1 Incision

The approach to the terrible triad begins with a rather extended incision. The incision is along the supracondylar ridge, then curves posteriorly, roughly over the anconeus-triceps interval and then along the subcutaneous border of the ulna (Fig. 19.2).



**Fig. 19.2** (a) Lateral incision on right elbow along supracondylar ridge, between the anconeus and triceps, continuing down the subcutaneous border of the ulna. (b) Incision for terrible triads

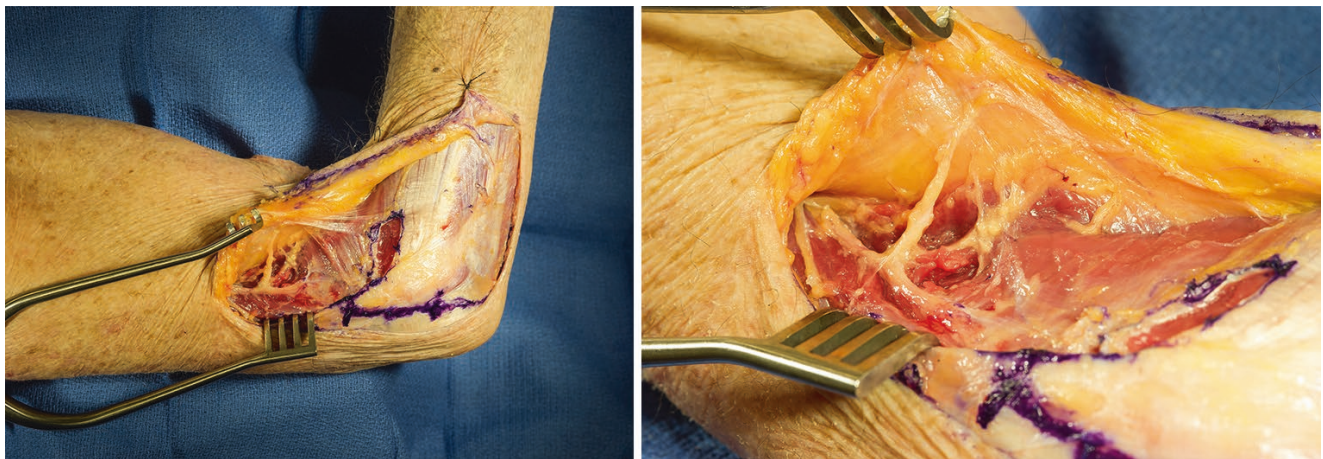


This incision creates a lateral flap, which is elevated over the lateral epicondyle and over the forearm extensors and tacked anteriorly with 2-0 nylon. Not uncommonly, there is no apparent soft tissue injury, except maybe a very small hole in the fascia proximal and posterior to the lateral epicondyle.

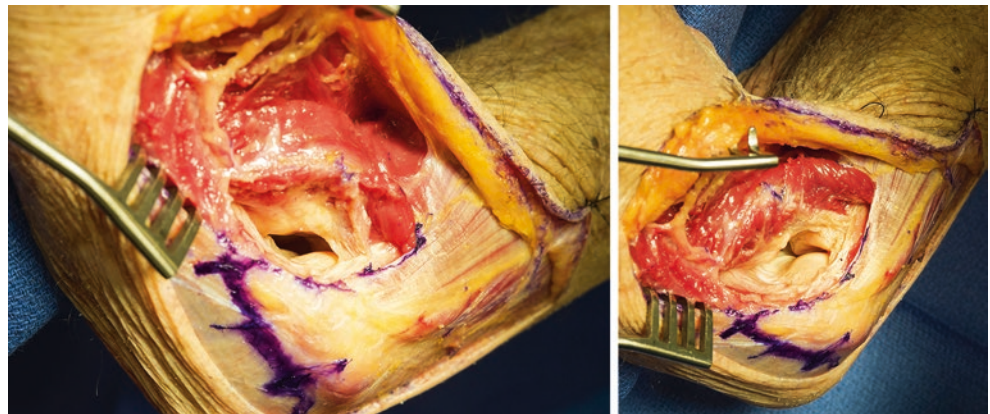
An anterior approach, if needed for a transolecranon fracture dislocation or terrible triad, is similar to the approach to the radial head, with an incision along the anterior aspect of the supracondylar ridge, lateral epicondyle, and lateral collateral ligamentous complex (Figs. 19.3, 19.4, and 19.5).



**Fig. 19.3** Inverted Y incision anterior to lateral epicondyle and radial collateral ligament and posterior between anconeus and triceps



**Fig. 19.4** Elevation of portion of the extensor carpi radialis longus and brevis with identification of the posterior radial collateral artery



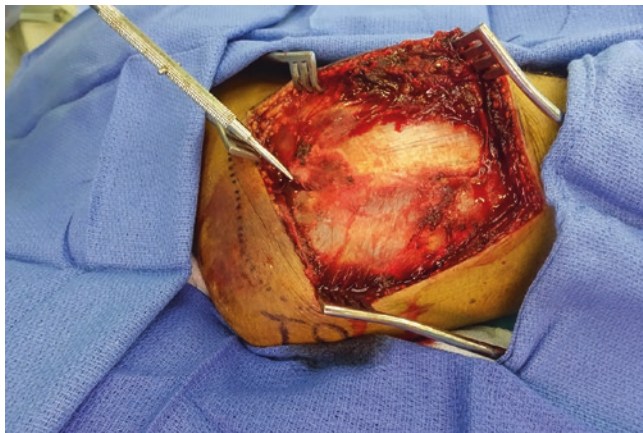
**Fig. 19.5** Anterior capsule elevated off humerus, exposing the capitellum and radial head

### 19.2.2 Approach to the Ulnohumeral Joint

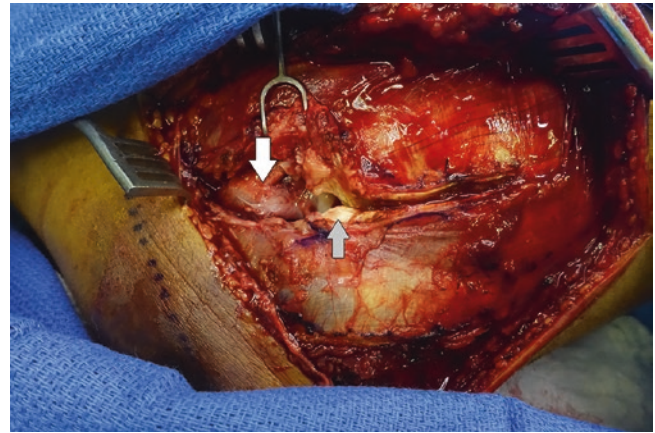
Following the fascial incision, the avulsion and sleeve effect of the lateral collateral ligamentous complex laterally off the epicondyle can be better appreciated. If a reduction has been

previously performed and the elbow has been reduced, the posterior subluxation can be appreciated with extension of the elbow (Figs. 19.6, 19.7, 19.8, 19.9, 19.10, 19.11, 19.12, 19.13, and 19.14).

**Fig. 19.6** Radiographs of right elbow terrible triad on presentation following transfer from an outside hospital

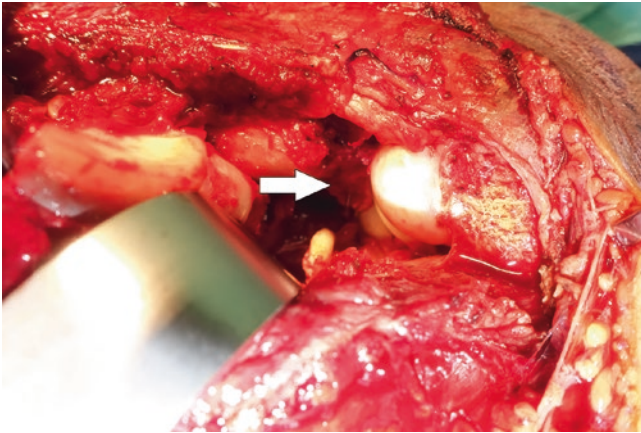


**Fig. 19.7** Right elbow terrible triad following incision and lateral flap elevation with characteristic limited rent in fascia over the epicondyle masking lateral ligament avulsion

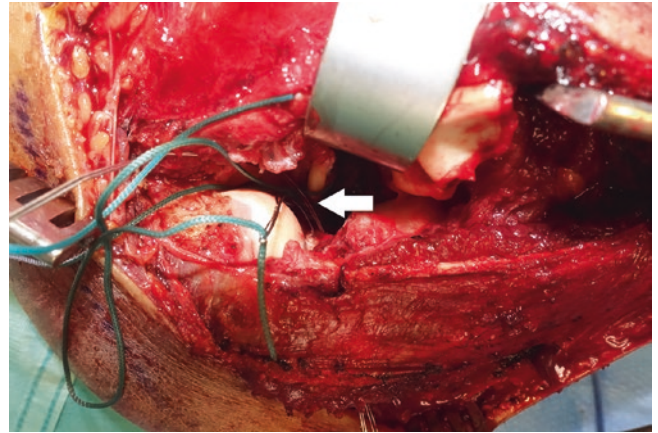


**Fig. 19.8** Anterior approach and incision extended along the extensor carpi radialis brevis (ECRB) and extensor digitorum communis (EDC) interval, demonstrating avulsion of lateral ligaments from the epicondyle (*white arrow*) and posteriorly subluxed radial head (*gray arrow*)

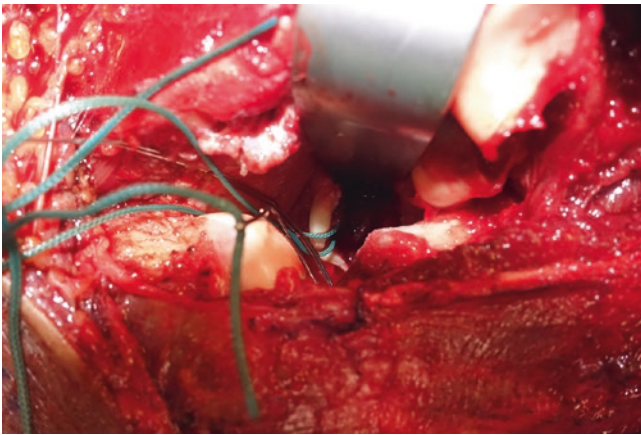




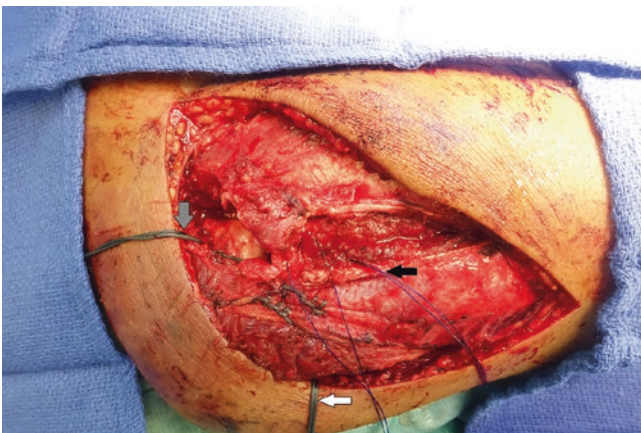
**Fig. 19.9** Lateral approach to coronoid process and coronoid base (arrow) through retracted radial head fragment



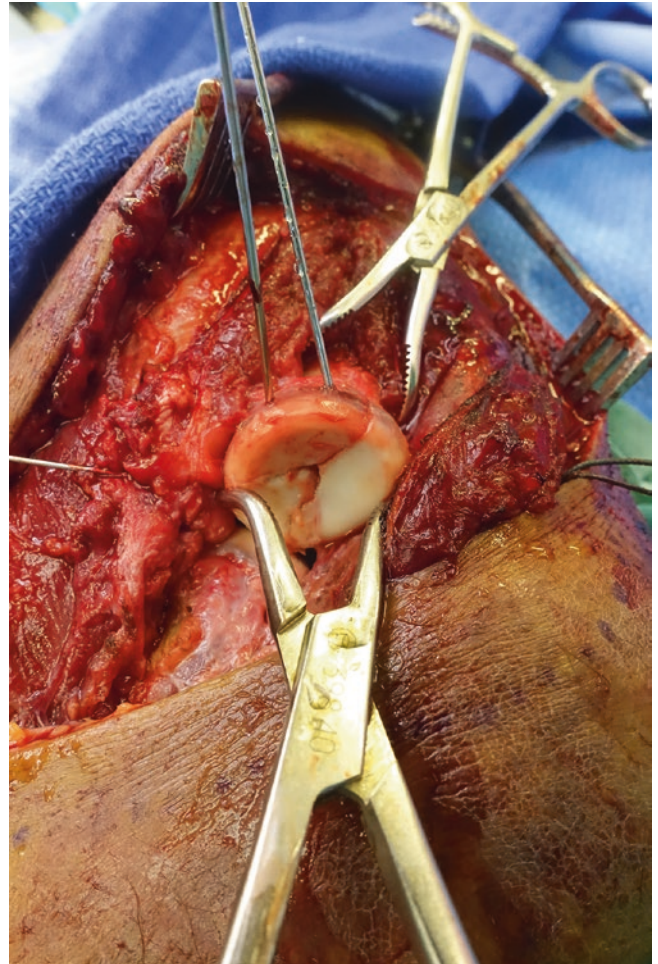
**Fig. 19.10** 24-gauge wire (arrow) passed through coronoid base fracture, with sutures through coronoid capsule juncture via drill holes



**Fig. 19.11** Sutures through coronoid



**Fig. 19.13** Sutures positioned in preparation for sequence of tying the annular ligament (black arrow), then the coronoid (white arrow) and lateral collateral (gray arrow)



**Fig. 19.12** Provisional reduction and fixation of radial head

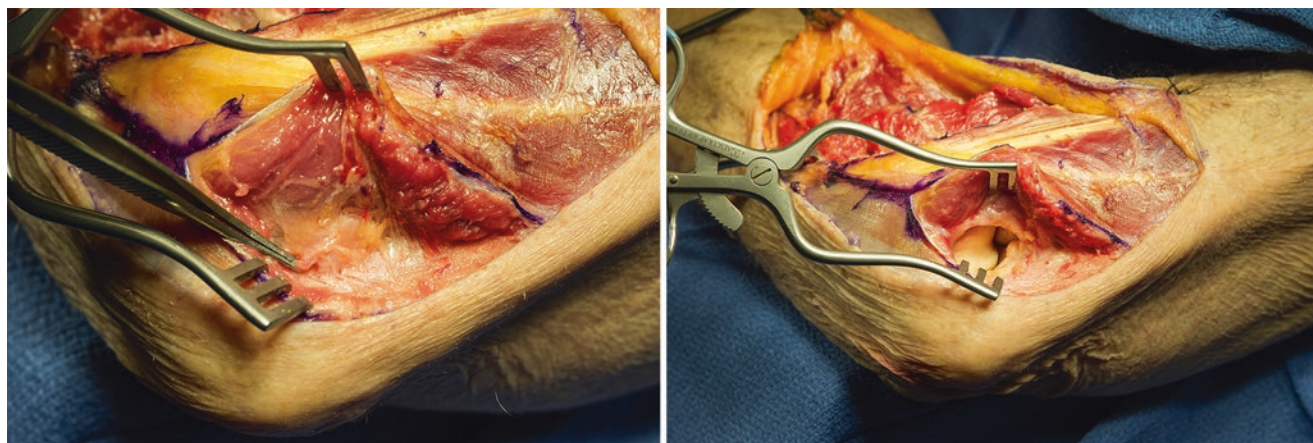


**Fig. 19.14** Radiographs following open reduction internal fixation (ORIF). Note drill holes through coronoid and olecranon (*arrow*)



I create a window between the triceps and the anconeus, acknowledging that there is potential for anconeus

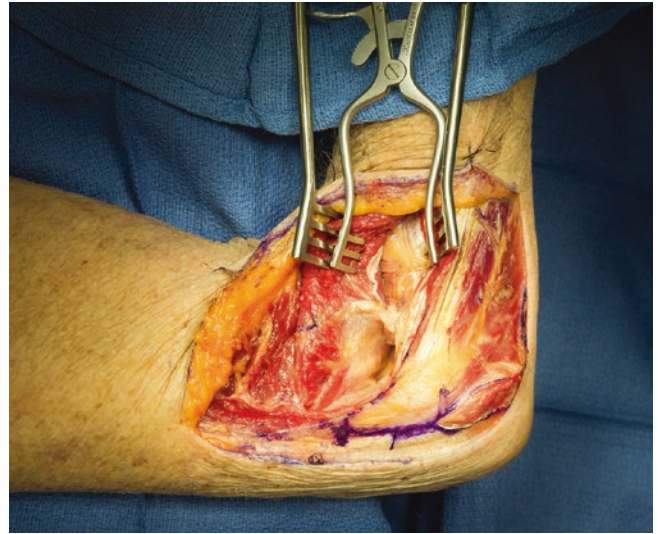
denervation (Figs. 19.15, 19.16, 19.17, 19.18, 19.19, and 19.20).



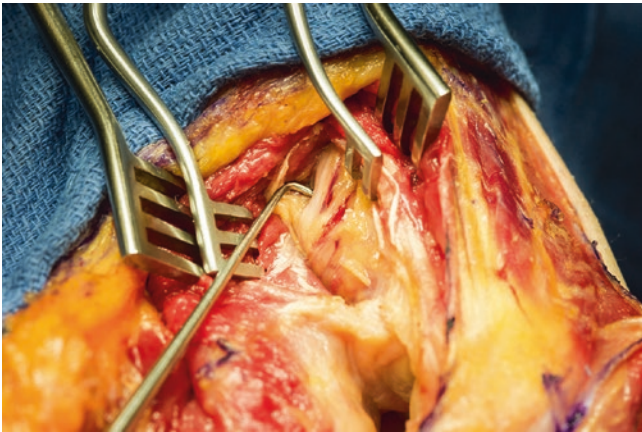
**Fig. 19.15** Anconeus elevated with posterolateral capsule in pick-ups, then excised, showing ulnohumeral and radiocapitellar joints



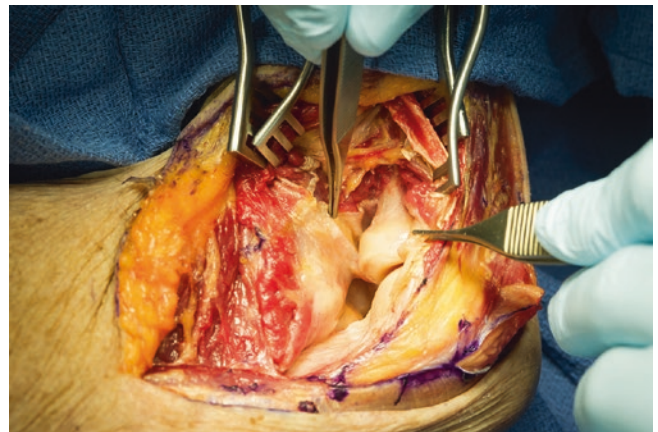
**Fig. 19.16** Plane developed between ECRB and EDC, with the deep fascia of brevis exposed



**Fig. 19.17** Brevis fascia divided, exposing the supinator



**Fig. 19.18** Probe pointing to posterior interosseous nerve after division of the superficial head of the supinator



**Fig. 19.19** Radial head and neck exposed after division of annular ligament in pick-ups



**Fig. 19.20** Fracture created in the radial neck

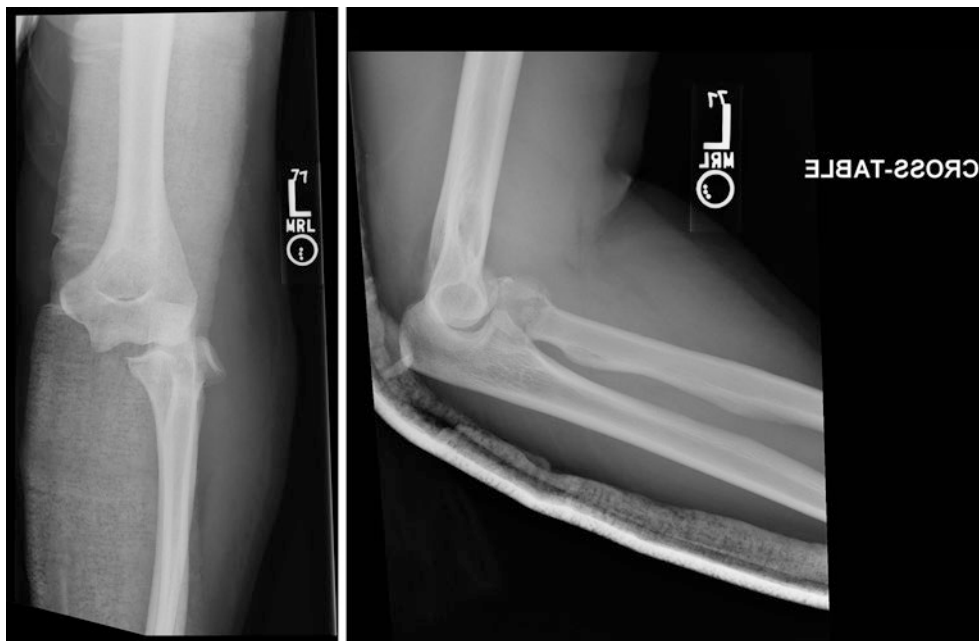


I believe it important to allow the ulnohumeral joint to be cleaned of any interposed debris. Doing so will also allow access to the coronoid base if there is a coronoid fracture (Figs. 19.21, 19.22, 19.23, 19.24, 19.25, and 19.26).

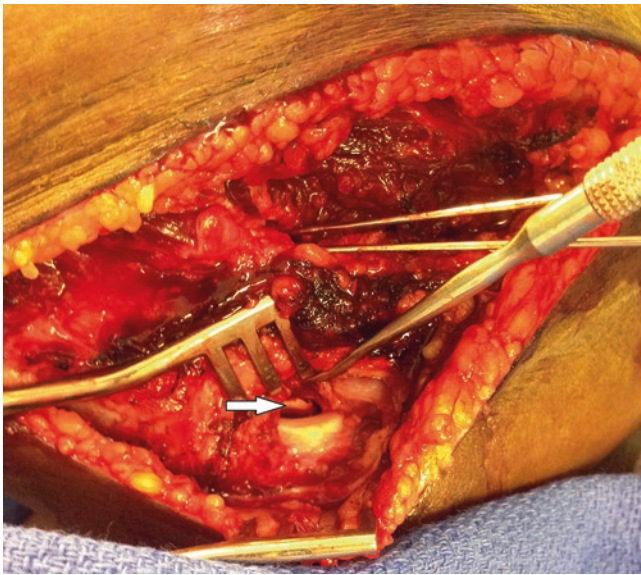
**Fig. 19.21** Injury radiographs of left elbow fracture dislocation



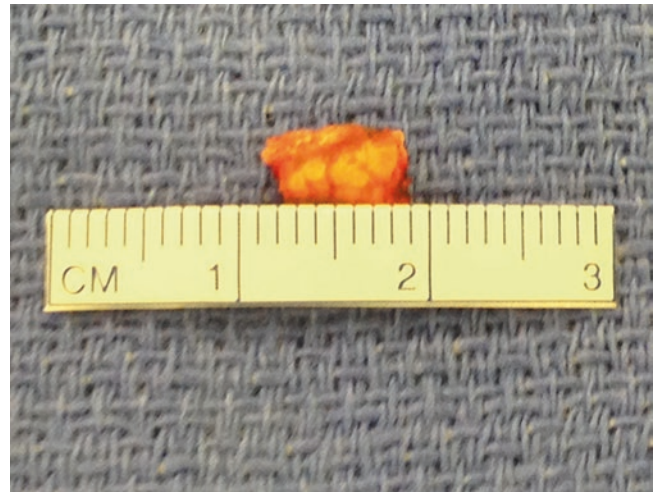
**Fig. 19.22** Radiographs following reduction without any apparent fragments in the joint







**Fig. 19.23** Exposure at the ulnohumeral joint through the anconeus triceps interval, demonstrating loose fragment in the joint (*arrow*). Hand is to the left

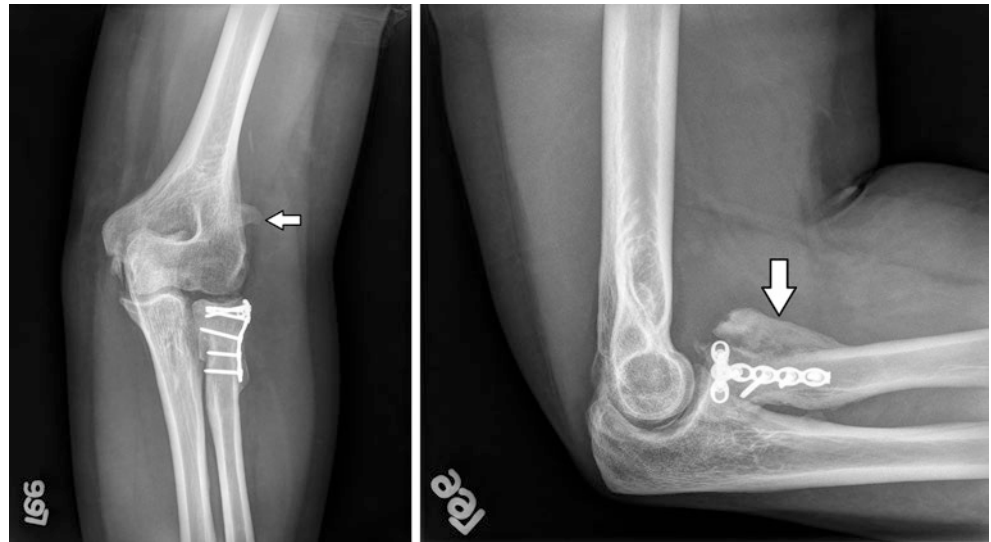


**Fig. 19.24** Intra-articular fragment after removal



**Fig. 19.25** Intraoperative radiographs following ORIF including cubital tunnel, Harris-Beath view of elbow, demonstrating ulnohumeral reduction

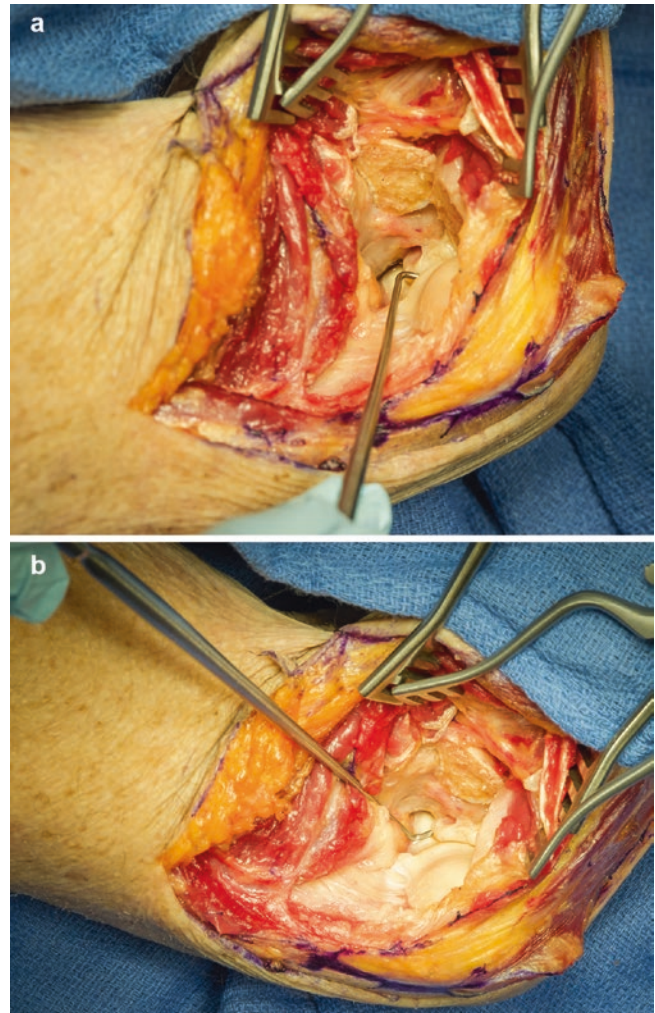
**Fig. 19.26** Late follow-up radiographs demonstrating significant heterotopic bone formation (*arrow*)



Great care must be paid to the insertion of the annular ligament at the crista supinatoris. If this is avulsed, it will need to be reinserted with either transosseous sutures, a plate, or anchors. The lateral collateral ligamentous complex frequently can be rotated distally to allow for visualization, but if adequate soft tissues remain attached to the lateral epicondyle, then the windows are between the triceps and anconeus posterolaterally and anterior to the lateral ligaments for access to the radial head.

### 19.2.3 The Coronoid

Depending on the status of the radial head, the radial head fracture can be used as a window to the coronoid process (Fig. 19.27).



**Fig. 19.27** (a) Radial head fragment flipped out of the way to visualize the coronoid. (b) Probe at coronoid tip

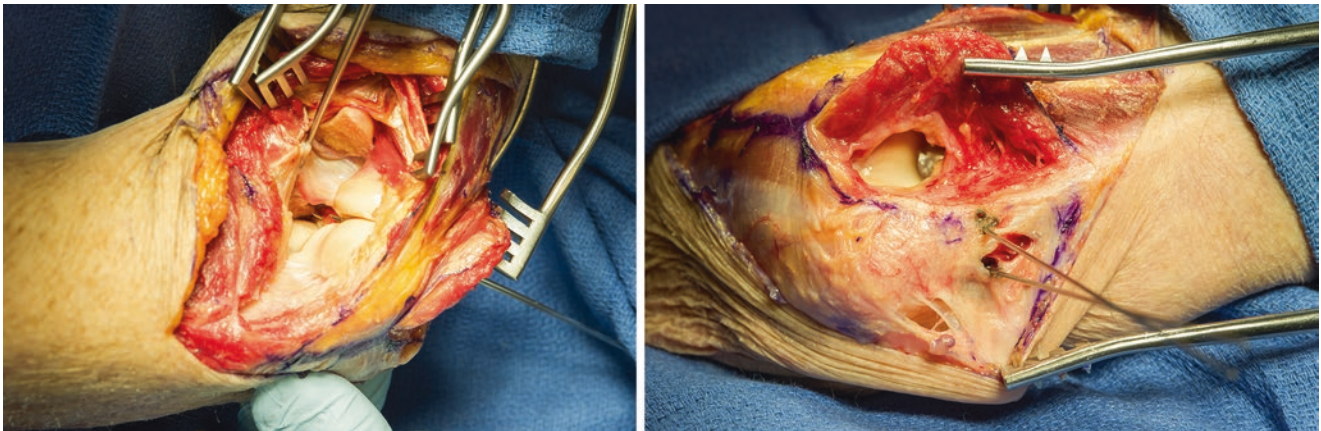


The coronoid fracture in a terrible triad is not uncommonly just at the tip or in the mid portion of the coronoid. It is also often comminuted. The necessity of type I or type II coronoid avulsion fracture fixation has been reviewed, with the conclusion that repair may not be required [6]. Regardless, I routinely demonstrate the stability imparted by the repair of the capsule or coronoid by relaxing and

tensioning sutures (using a loop technique with #5 Ethibond Excel<sup>®</sup>), showing the potential subluxation or dislocation when the sutures are lax. This can be difficult in the coronoid fragment, if it is comminuted. The sutures will not pass through the bony fragments, but need to pass through the capsule at the capsule-coronoid juncture (Figs. 19.28 and 19.29).



**Fig. 19.28** Coronoid tip, osteotomized “fractured”

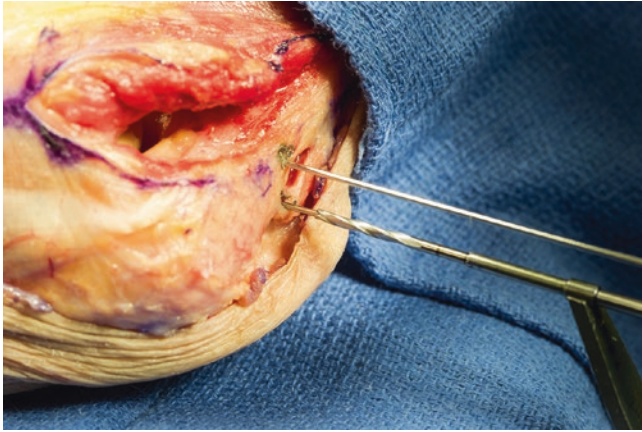


**Fig. 19.29** Two 3.0-mm cannulated guide wires with screw-threaded tips positioned dorsal to anterior at the coronoid base fracture

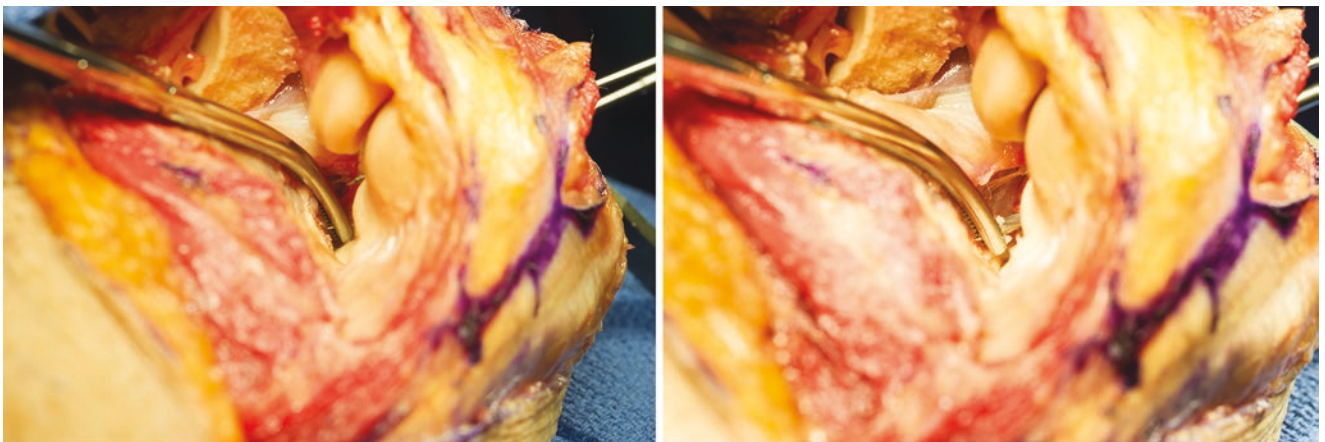


The holes in the ulna and coronoid base are drilled using the dislocated position for placement of the guide wires for my subsequent suture passage. Through the dorsal surface of the ulna, I place 1.1-mm threaded-tip guide wires from the 3.0-mm Synthes® cannulated screw set. Under direct visual-

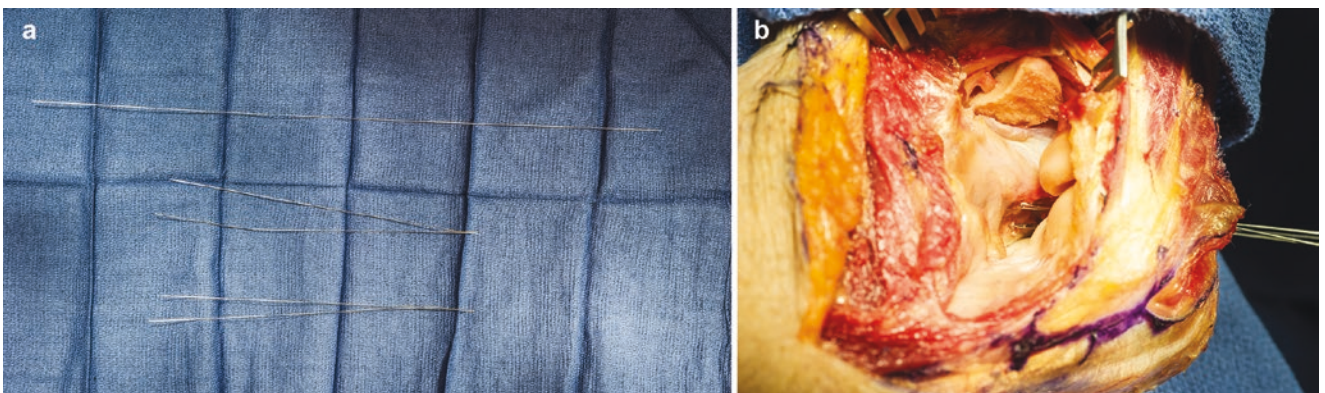
ization, with the elbow dislocated, the holes are drilled using the 2.0-mm cannulated drill bit over the guide wires, and the 24-gauge interosseous wires are passed (Figs. 19.30, 19.31, 19.32, and 19.33).



**Fig. 19.30** Cannulated drill bit over guide wires

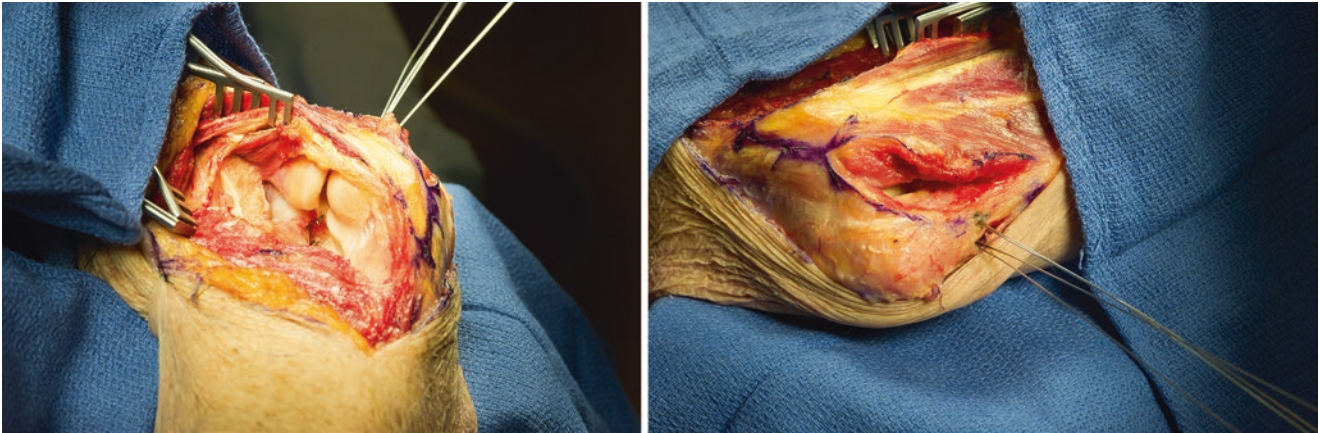


**Fig. 19.31** Hemostat grabbing tip of guide wire to prevent advancing wire when drilling



**Fig. 19.32** (a, b) Looped 24-gauge wire to be used as suture passer





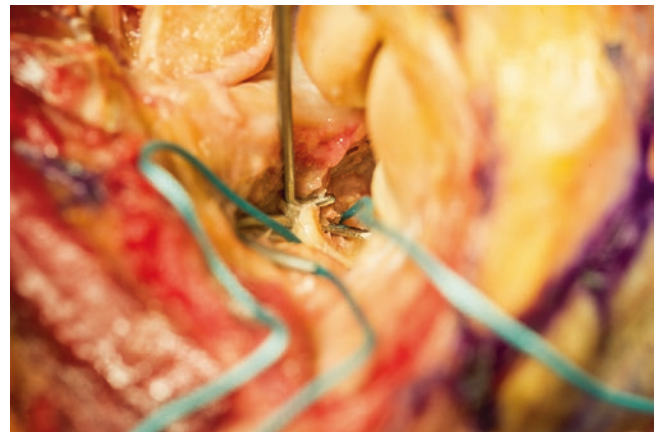
**Fig. 19.33** Wires placed for suture retrieval

Drill holes are then made in the coronoid fragment using a 2.0-mm drill bit (not the cannulated bit), if the fragment is of adequate size, or through the capsule fragment juncture if the

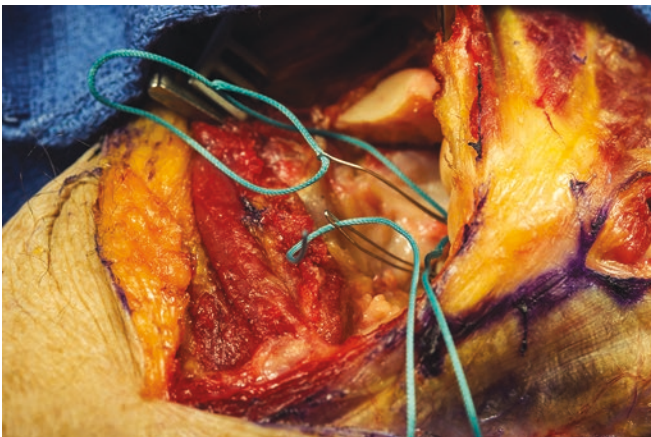
coronoid is comminuted. A 5-0 Ethibond® suture is placed through these holes (Figs. 19.34, 19.35, 19.36, and 19.37).



**Fig. 19.34** 2.0-mm drill hole in coronoid tip fragment. This step, with passing of #5 Ethibond Excel® suture, is tricky and frustrating

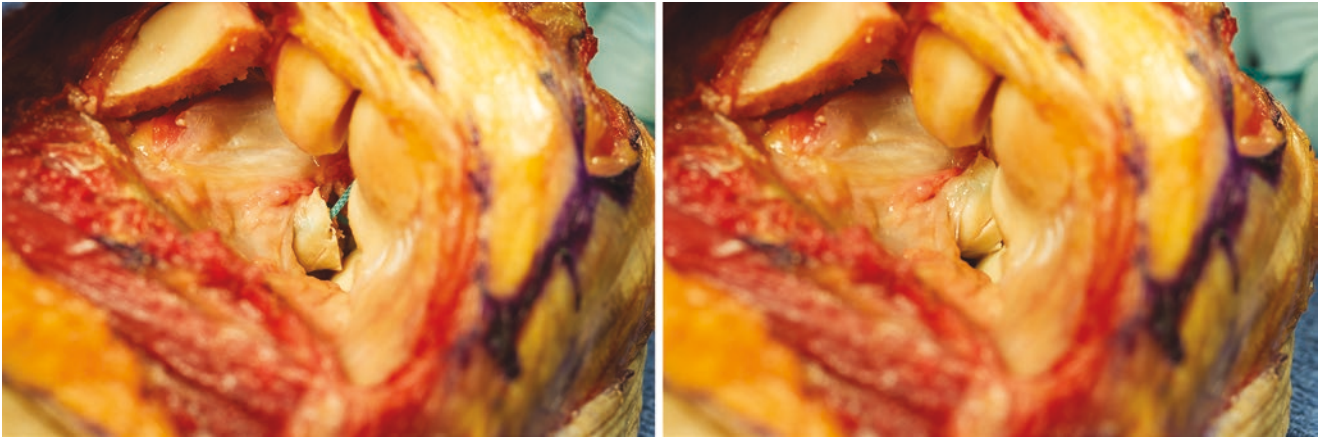


**Fig. 19.35** Passing #5 Ethibond Excel® suture through coronoid tip fragment. Don't force the needle and break the bone



**Fig. 19.36** Free ends of suture in wire passer



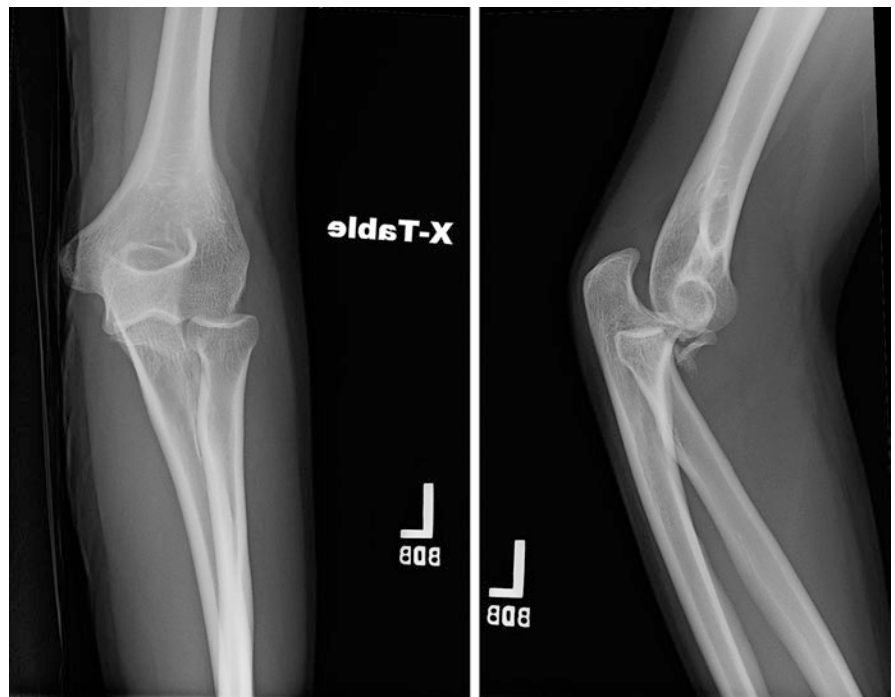


**Fig. 19.37** Tensioning and test seating of coronoid fragment. Don't get emotional and pull too hard or try too many times and break the fragment

This is easier said than done. It can be somewhat of a struggle because of the difficulty in turning your hand to get the suture passed through the coronoid fragment capsule. The needle is cut and the sutures are looped into the 24-gauge interosseous wires and then pulled through holes in the ulna

to be tied over the dorsal cortex. If the fragment is large enough, I will frequently use a 0.0625-in. or 5/64 threaded Steinmann pin along with a smooth K-wire to hold this fragment (Figs. 19.38, 19.39, 19.40, and 19.41).

**Fig. 19.38** Injury radiographs of left elbow fracture dislocation





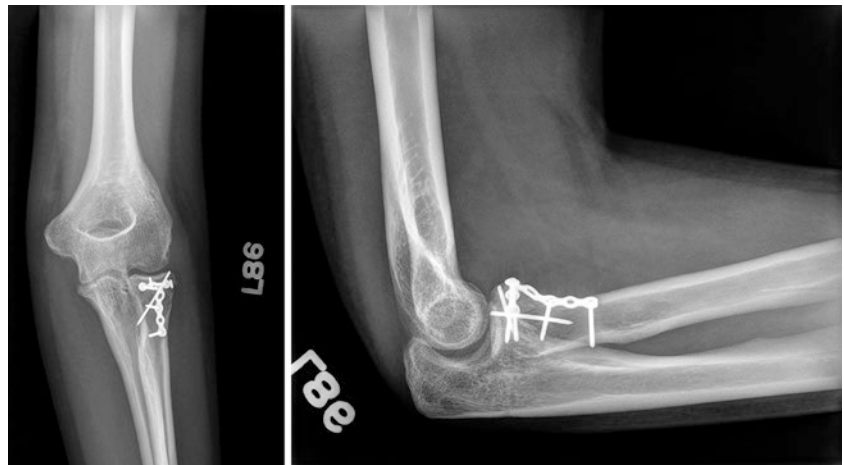
**Fig. 19.39** Splinting radiographs following reduction prior to ORIF



**Fig. 19.40** Radiographs following ORIF in splint, demonstrating Kirschner wire (K-wire) fixation of coronoid



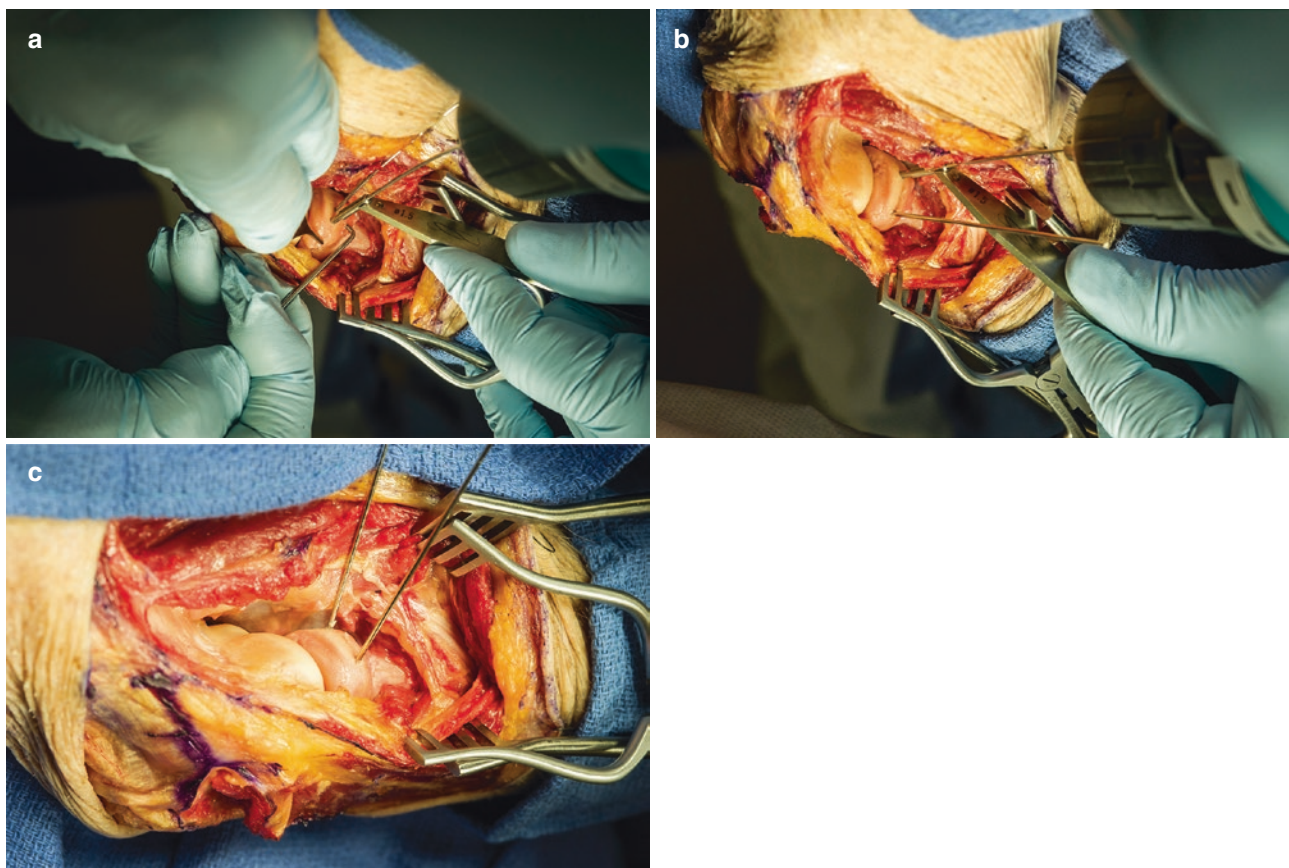
**Fig. 19.41** Radiographs following K-wire removal 4 months from original injury



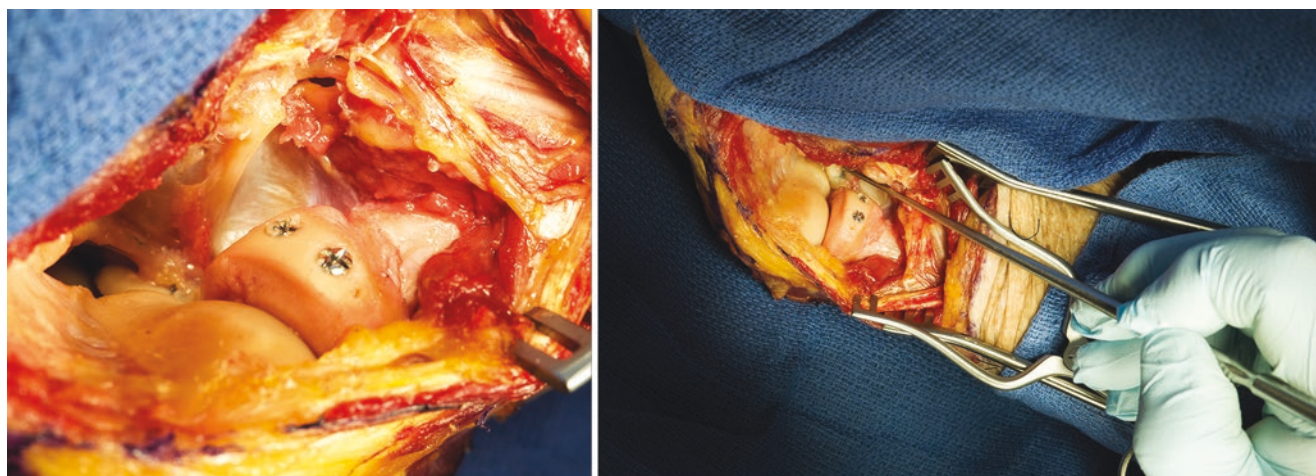
### 19.2.4 The Radial Head

With the wires preplaced and the K-wires preplaced in the coronoid base if the fragment is big enough for fixation, the reduction of the coronoid fragment is then carried out; the K-wires are advanced under direct visualization through the radial head defect, and the reduced fragment can be held with a dental pick. Once reduction is confirmed, I generally

proceed with the radial head fixation before tying the suture dorsally, in an effort to prevent shearing of the coronoid fragment. The sutures and K-wires have been preplaced, and the suture will be tied after the radial head fixation is completed. The larger coronoid fragments are usually associated with transolecranon fracture dislocations. (See Chap. 17, on that topic, for other methods of coronoid fixation.) Radial head fixation is then carried out (Figs. 19.42 and 19.43).



**Fig. 19.42** (a–c), Radial head reduction and fixation, K-wires first. Consider placing where screws may go to sequentially swap out wires for screws



**Fig. 19.43** Screws in place. I generally use headless screws, but mini-fragment 1.5-mm screws were used in this demonstration

If radial head replacement is selected, I prefer to use a bipolar head, using the guidelines of radial head alignment relative to the coronoid. Initial studies demonstrated equal results in biomechanical testing of monoblock versus bipolar replacements, except that with the forearm in neutral rotation, neither performed as well as the native radial head [7].

Subsequent studies showed similar results with monoblock and native radial heads, with subluxation demonstrated using the bipolar head [8]. I favor a bipolar system because I like how it seems to self-fit to the capitellum, but I acknowledge good clinical results with either system (Figs. 19.44, 19.45, and 19.46).

**Fig. 19.44** Injury radiographs of elbow fracture dislocation



**Fig. 19.45** Radiographs following closed reduction with radial head displacement





**Fig. 19.46** Follow-up radiographs following open reduction, ligament repair, and radial head replacement arthroplasty. Note heterotopic ossification and wire around the neck to prevent splitting of the neck and fracture line propagation



Evaluation of the joint space of the ulnohumeral joint is important to avoid overstuffing or inserting a short radial head [9, 10]. On an anterior/posterior radiograph, the lateral joint space of the ulnohumeral joint should be slightly wider than medially. Finally, if there are issues, evaluate the opposite side for ulnar variance to assist in restoration of the forearm length.

### 19.2.5 Ligaments

With fixation complete or replacement carried out, it is very important not to let the elbow re-dislocate. The lateral collateral ligamentous complex can now be repaired. For this purpose, I use transosseous drill holes through the lateral epicondyle at the projected insertion site, exiting posteriorly and anteriorly (Figs. 19.47 and 19.48).

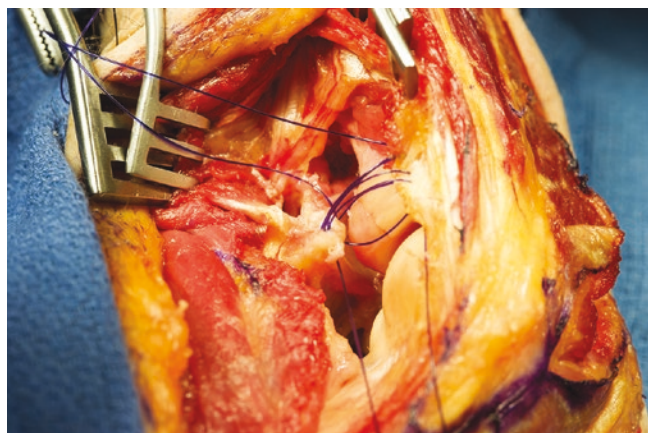


**Fig. 19.47** Drill holes in lateral epicondyle for lateral collateral ligament (LCL) reinsertion repair using a 2.0-mm drill bit



**Fig. 19.48** Krackow technique is used to place #2 Ethibond Excel® in the LCL complex. The suture is then passed using 24-gauge looped wires. Note that the suture is placed so that the deep surfaces will likely be brought to the epicondyle

I use a 2-0 Ethibond® suture in a Krackow weave through the lateral ligaments, then I pass through the drill holes with 24-gauge interosseous wires. With the sutures now placed, I also place the 2-0 PDS® sutures in the annular ligament (Fig. 19.49).



**Fig. 19.49** Placing two 2-0 PDS® buried figure-of-eight sutures in the annular ligament. Place both before tying one

My sequence of suture tying is the annular ligament suture first, followed by the coronoid or anterior capsule suture, followed by the tying of the lateral ligamentous complex sutures (Fig. 19.50).



**Fig. 19.50** Sutures tensioned

All these will sequentially tension the preceding repairs (Fig. 19.51). The fascial approximation is carried out with buried 2-0 PDS® sutures.



**Fig. 19.51** Don't tie any sutures until all three—coronoid, annular ligament, and LCL—are placed. The tying sequence is annular ligament, coronoid, then LCL. This sequentially tightens the preceding repair

At this point, allow me a disclaimer regarding the medial collateral ligament. Only during open injuries do I routinely address the medial collateral ligament. Residents have asked, “Do I stress the elbow after the open reduction, to determine whether medial collateral ligament repair is necessary, versus external fixation?” My response is that if I have a concentric reduction and I am happy with the repairs to the lateral ligament, radial head, and coronoid, I see very little reason to stress the medial side. If I am concerned about the degree of comminution or instability, I usually decide to apply external fixation before I get to the point of considering whether to stress the complex. Because of difficulties with attaining therapy for elbows with hinged fixtures, I have gone to more static fixators with two half-pins in the humerus just proximal to the supracondylar ridge, two pins in the ulna, and two in the index metacarpal. Therefore I almost never address the medial side.

The closure is then carried out in layers with a drain. I place the patient in a splint with the elbow flexed to 90° and the wrist extended to relax the wrist extensor repair,

with very slight pronation, unless an external fixator was applied.

### 19.3 Patient Rehabilitation

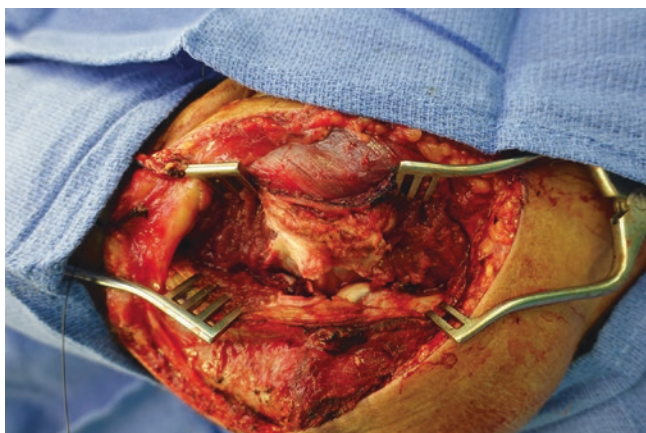
My patient’s range of motion program begins with the first postoperative clinic follow-up. The patient is allowed elbow flexion/extension from 60° of extension to full flexion and full pronation/supination at 90° of elbow flexion. The patient is then allowed to extend 15° further each week, so that full range of motion is allowed (but not necessarily attained) by 4 weeks. At 6 weeks, the patient comes out of the splint, and at 6–8 weeks is directed to general strengthening, with dynamic splinting if required. Weight-bearing is allowed at 3 months after surgery.

Patients are counseled about the possible need for subsequent capsulectomies, although this is an uncommon scenario (Figs. 19.52, 19.53, 19.54, 19.55, 19.56, 19.57, 19.58, 19.59, 19.60, 19.61, 19.62, 19.63, 19.64, and 19.65).

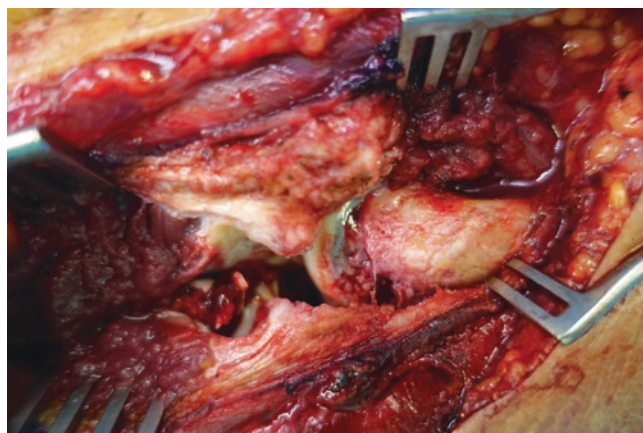


**Fig. 19.52** Injury radiographs of left elbow fracture dislocation





**Fig. 19.53** Approach to left elbow, exposing capitellum

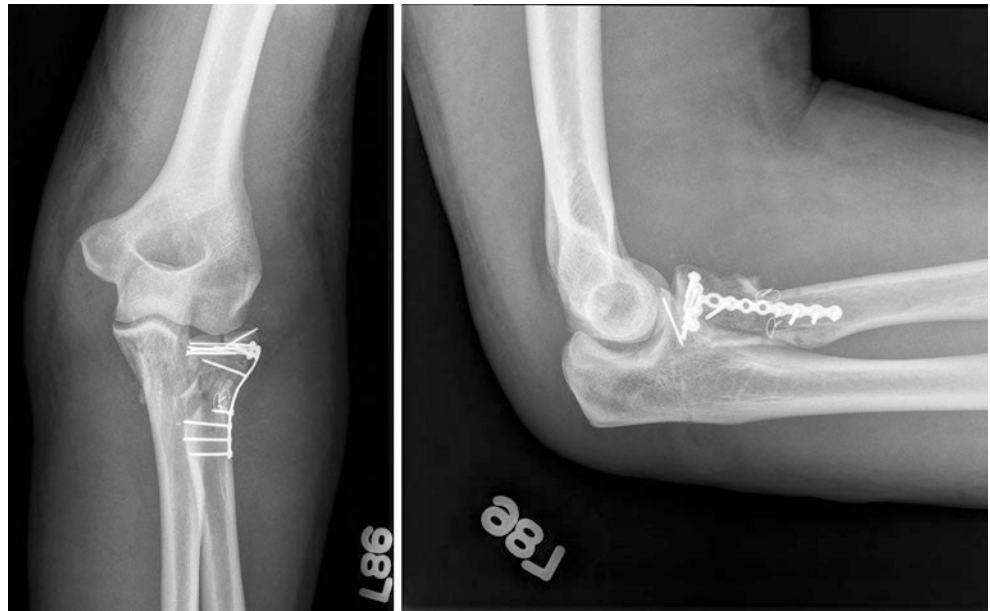


**Fig. 19.54** Extension demonstrating lateral soft tissues avulsed off the epicondyle as a sleeve



**Fig. 19.55** Reaching through a radial head defect with needle holders holding guide wires to prevent the wires from advancing while over-drilling

**Fig. 19.56** Radiographs following ORIF. Note lack of support medially and extended span. Replacement was not performed because the required neck length was not available



**Fig. 19.57** Follow-up radiographs with wandering K-wires. The patient had returned to construction work with no complaints. The K-wires were subsequently removed

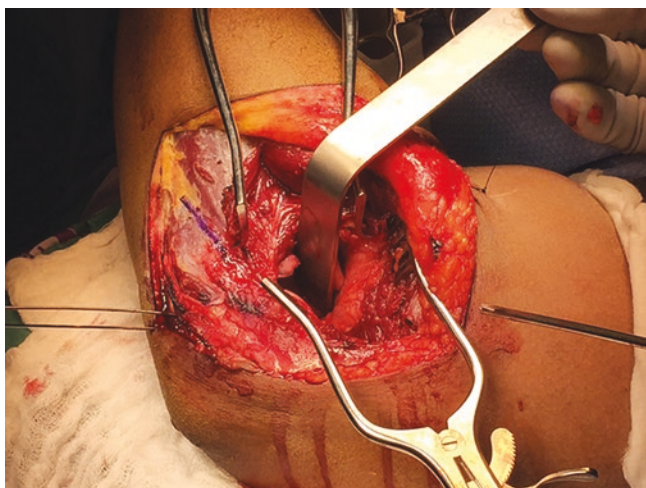


**Fig. 19.58** Injury radiographs of left elbow terrible triad injury

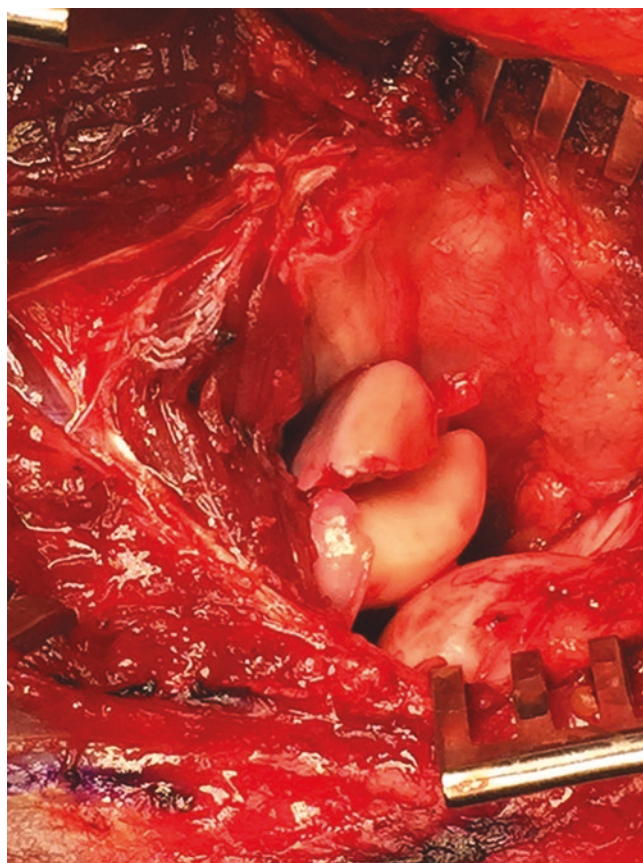


**Fig. 19.59** Radiographs following closed reduction

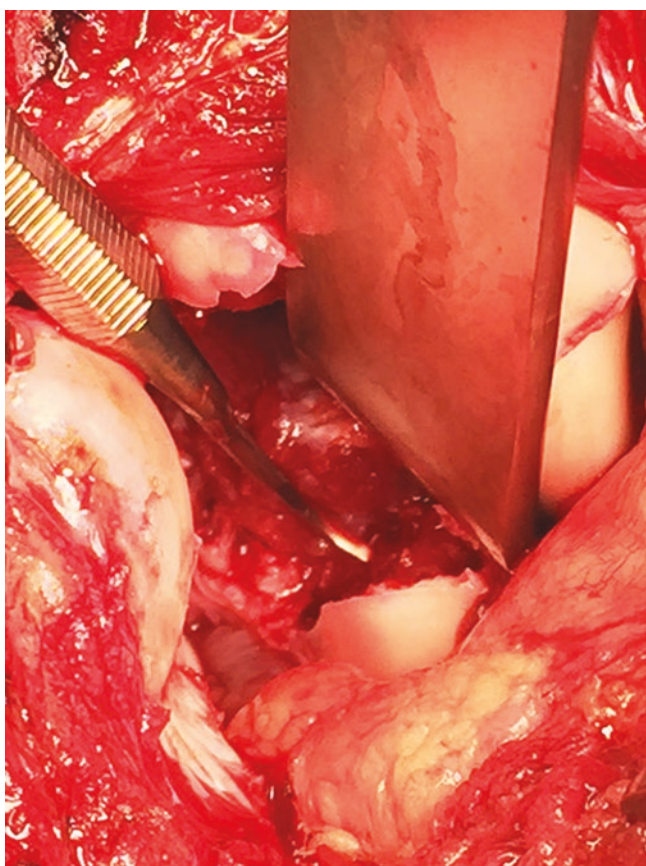




**Fig. 19.60** Lateral approach to left elbow anterior to lateral epicondyle with intact LCL

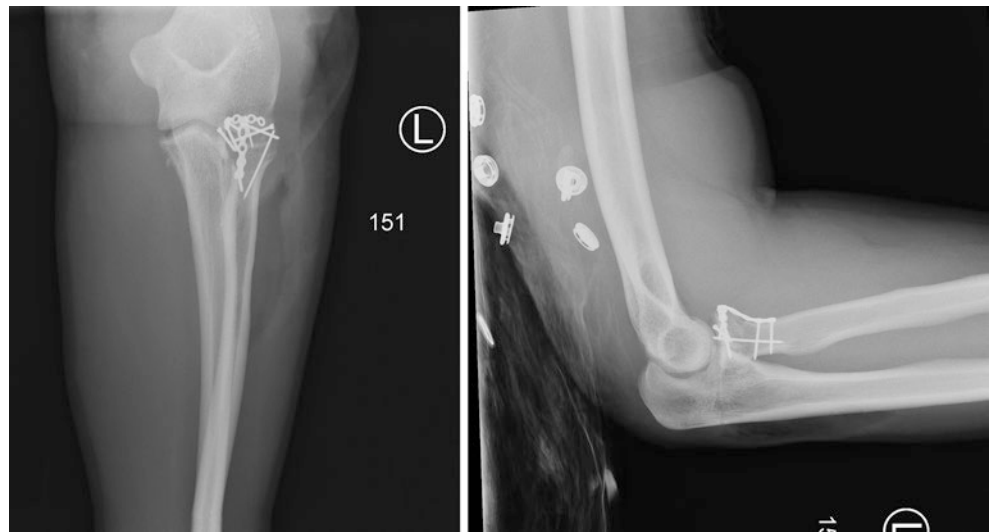


**Fig. 19.61** Comminuted radial head exposed

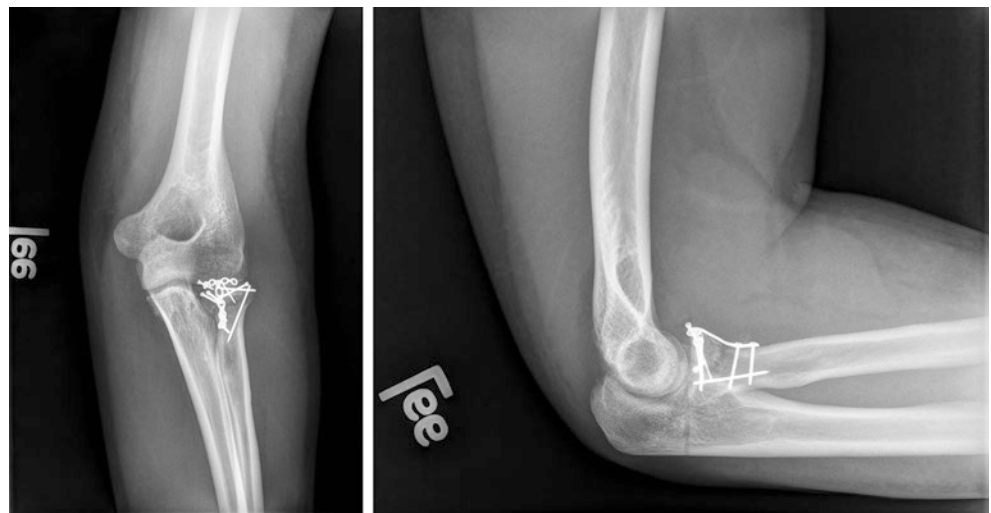


**Fig. 19.62** Freer elevator pointing to coronoid fragment

**Fig. 19.63** Intraoperative radiographs following ORIF



**Fig. 19.64** Follow-up radiographs demonstrating screw backing out



**Fig. 19.65** Follow-up radiographs following screw removal with healed radial head fracture



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## 20.1 Monteggia Fracture Types

The term *Monteggia fracture* immediately conjures up the mental image of a specific fracture pattern, probably one of the first patterns learned by orthopaedic residents [1–3]. Along with a forearm with an ulnar fracture and a dislocated radial head, the orthopaedic resident also should have the understanding of open reduction internal fixation (ORIF) of the ulna with closed reduction of the radial head. The resident also should know the potential association of ORIF with a posterior interosseous nerve (PIN) injury.

Frequently, a resident will be queried as to the type of Monteggia fracture; for this, we need to give credit to J.L. Bado for classifying the four types [4]:

- Type I is ulnar shaft fracture with anterior radial head dislocation (Fig. 20.1).
- Type II is ulnar shaft fracture with posterior radial head dislocation (Fig. 20.2).
- Type III is ulnar shaft fracture with lateral radial head dislocation (Fig. 20.3).
- Type IV is ulnar shaft fracture, radial head dislocation, and associated radial shaft fracture or radial head dislocation (Fig. 20.4). Another way to remember Type IV is to think of it as both a bone forearm fracture and a radial head dislocation.

**Fig. 20.1** Bado Type I anterior dislocation. This case represents an irreducible radial head



**Fig. 20.2** Bado Type II posterior dislocation. Note the radial head fracture



**Fig. 20.3** Injury radiographs of right arm Bado Type III fracture dislocation



**Fig. 20.4** Injury radiographs of Bado Type IV fracture dislocation





## 20.2 Confusions Relating to Monteggia Fractures

By definition, the fractures of the radius and ulna are in the proximal third of the forearm and at the same level, which seems a little constricting from an inclusion standpoint. Equivalents are also described by Bado, which can be confusing because of the wide spectrum of locations of associated fractures in the radius and the ulna. So let's stick with the four basic types.

Confusion also arises in discussions and reports of Monteggia fractures that include transolecranon fracture dislocations. These types of fractures are known as *Monteggia variants* and should be considered a separate entity.

"What is the most common type of Monteggia fracture?" is frequently asked. Relative to frequency, Ring *et al.* [5] have stated that Type II is the most common, yet they exclude anterior transolecranon fracture dislocations but include posterior transolecranon fracture dislocations. The report by Ring *et al.* references a previous report by Jupiter *et al.* [6] specific to posterior dislocations, including a subset classification of Type II, from which some patients were included, thus biasing the frequency towards Type II as most common. Konrad *et al.* [7] had a similar opinion concerning frequency but included transolecranon fractures in their data. Looking at a group of patients with Monteggia fractures that involved the shaft only, Eglseider and Zadnik [8] found Type I to be the most common. This finding supported an earlier report by Reynders *et al.* [9]. Because of the inclusion of transolecranon fractures, it is difficult to tease out the data to determine the most common type. The discussion becomes even more confused with the inclusion of pediatric patients in various reports; they probably should be looked at as a separate group [10, 11]. Nevertheless, the usefulness of knowing the frequency of various types (except for test-taking purposes) escapes me.

## 20.3 Radial Head Reduction

Another issue to address is the radial head reduction. Considering the occurrence of incarcerated structures, such as the posterior interosseous nerve, biceps tendon, and annular ligament, which can block reduction, the chant "Redo the ulna ORIF" needs to be reexamined if the radial head is not reduced. As has been reported, the radial head reduction is not a slam dunk [12–14]. One report [8] shows a 14% (one in seven) frequency of irreducible radial head dislocations.

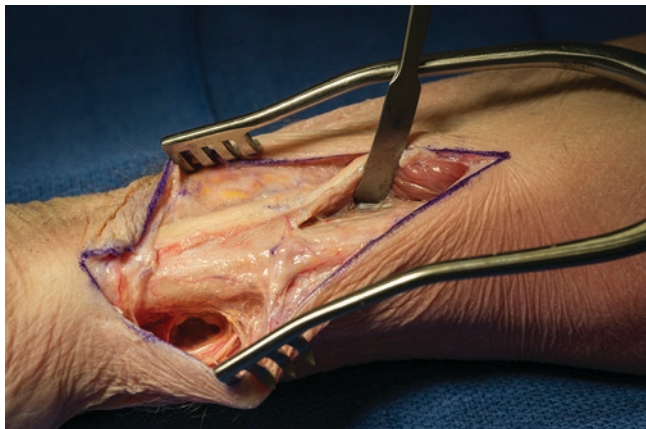
In reports of pediatric Monteggia fractures, annular ligament repositioning and joint exploration, rather than reconstruction or revision of the internal fixation, have been advocated, even in the face of a supposedly reduced radial head [15, 16]. In all cases, the approach of joint exploration somewhat belies the extended history of Monteggia ORIF with successful radial head dislocation reductions, as well as the apparent rarity of required subsequent intervention. This may, in fact, not be the case, however, as very close examination of the radiocapitellar joint may reveal that true reduction and congruity have not been obtained, yet the arm is able to maintain function.

Outcomes for these injuries are actually good, especially considering the nature of the fracture and the energy required to create it. Regardless, a very exacting inspection on multiple views of the radiocapitellar joint is required, and direct visualization may be indicated. I have never revised any primary ulna fixation to attain radial head reduction; instead, I explored the radiocapitellar joint and addressed the pathology that blocked the reduction.

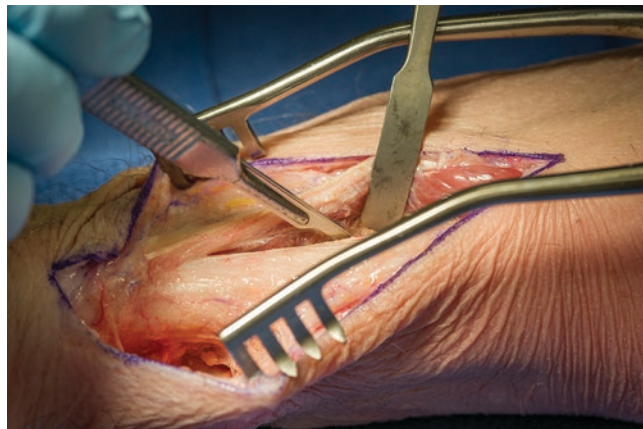
## 20.4 Surgical Approach

In order to extend the surgical field access without concern for a break in sterility, I use a sterile tourniquet when treating Monteggia fractures, just in case the elbow needs to be

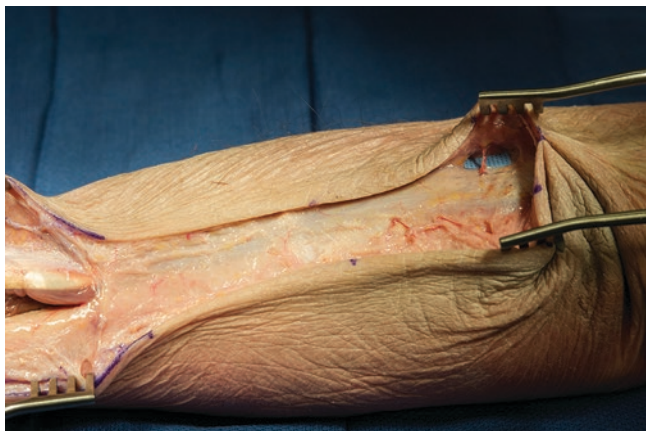
approached. (Patient prepping and draping for this procedure is presented in Chap. 15.) I approach the fracture using a dorsoulnar incision, just dorsal to the subcutaneous border of the ulna. The incision is performed down to the fascia (Figs. 20.5, 20.6, and 20.7).



**Fig. 20.5** Distal exposure of ulna with the retractor reflecting the extensor carpi ulnaris and dorsal surface of the ulna



**Fig. 20.6** Sharp extraperiosteal elevation of the extensor carpi ulnaris (ECU)



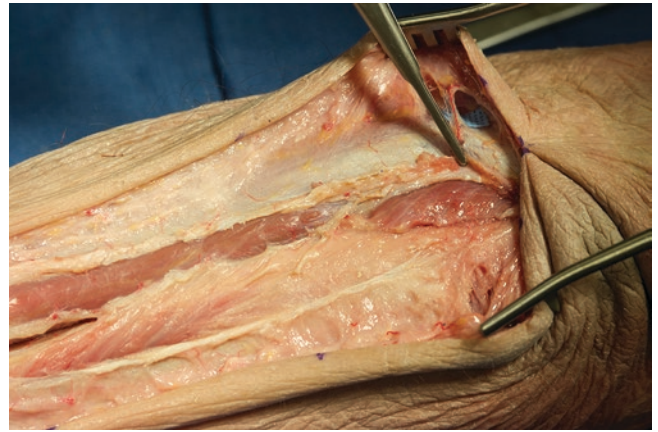
**Fig. 20.7** Incision carried proximally with blue background under the radial recurrent artery perforator to skin

I prefer to start my approach distally, as this will allow visualization of the extensor carpi ulnaris (ECU) tendon, which makes the subsequent elevation easier. Once the tendon is identified with gentle retraction, a rather clear plane can be developed between the dorsal aspect of the ulna and the ECU. The dissection is then continued proximal with the frequently encountered interdigitation of the flexor carpi ulnaris (FCU) and the ECU muscle bellies (Fig. 20.8).



**Fig. 20.8** Forearm fascial incision carried proximally showing interdigitation of the flexor carpi ulnaris (FCU) with the ECU

Dissection is performed adequately to allow four screws proximal and four screws distal to the fracture (Fig. 20.9).

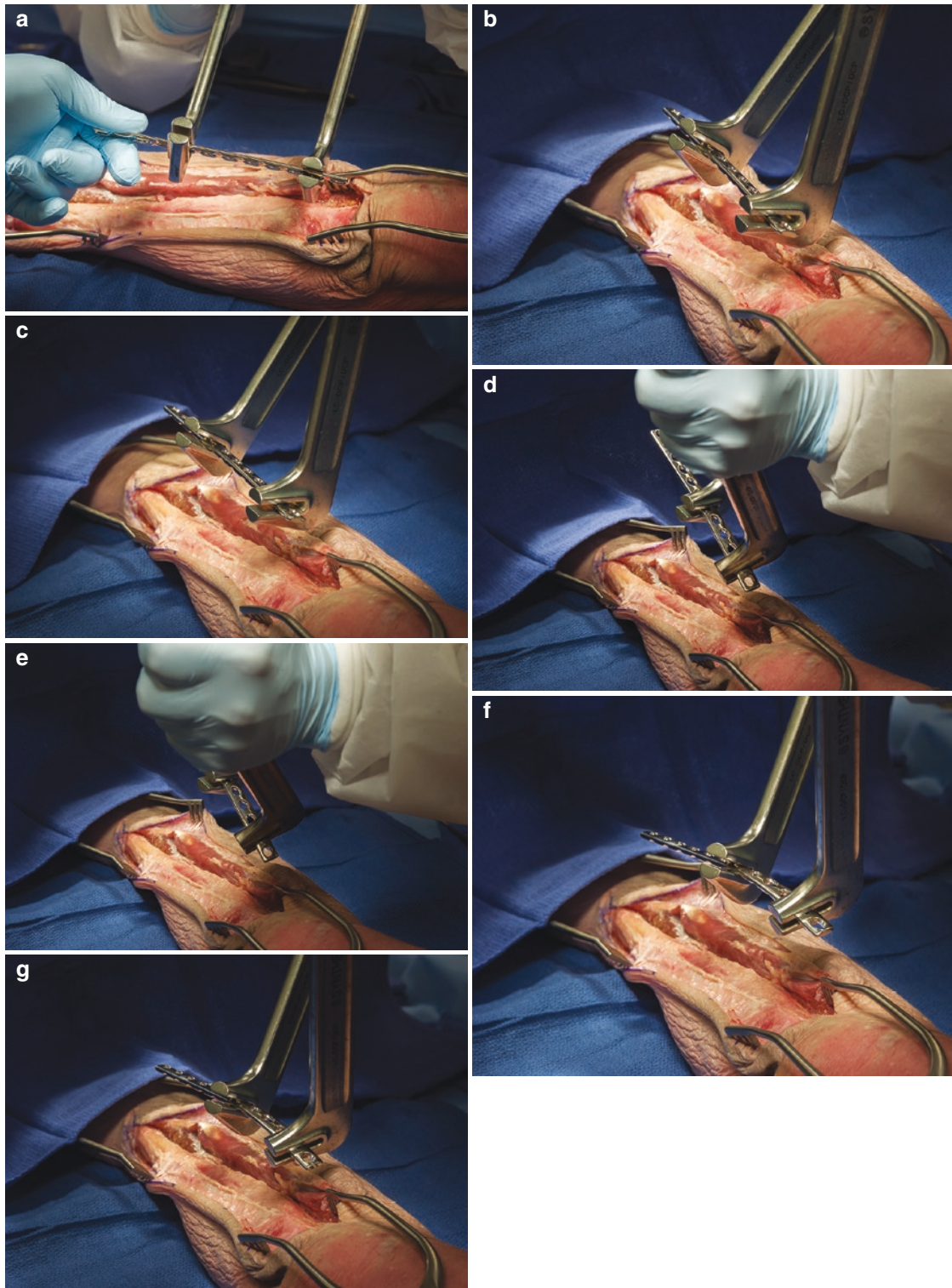


**Fig. 20.9** Anconeus exposed proximally



## 20.5 Reduction, Fixation

In the proximal aspect of the ulna, there is a bow and curve of the ulna that will require the plate to be twisted and bent (Figs. 20.10 and 20.11).



**Fig. 20.10** (a–g) Plate contouring using a 3.5-mm limited contact–dynamic compression plate (LC-DCP) incorporating twist and bend at the same time to fit the proximal ulna curve and bow



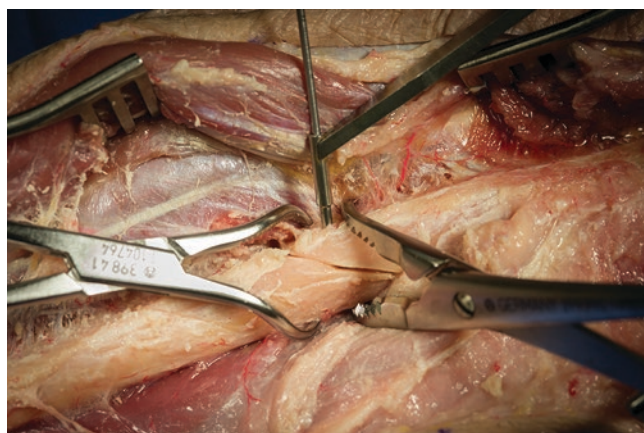


**Fig. 20.11** Plate positioning tested prior to fixation

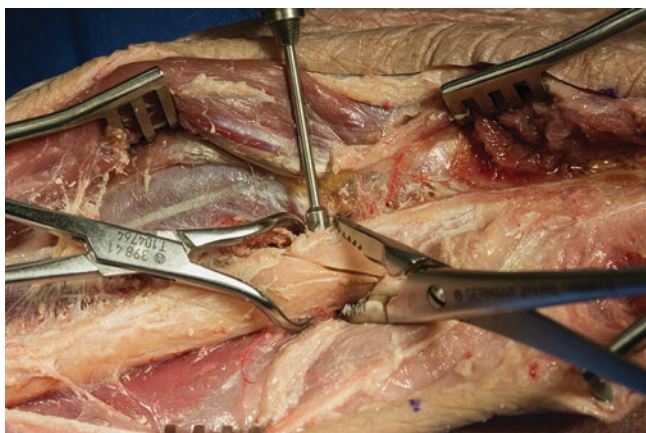
With the distal half of the ulna, I rarely bend the plate because of the relatively flat contour of the dorsal surface. I prefer the dorsal surface for plating, acknowledging the greater potential for ECU irritation than with anterior plating because the patient is more likely to rest the arm on the more anterior aspect. (Though there is one group of individuals who use the dorsal aspect of the arm for various activities: interior linemen on football teams.) Once the fracture is visualized, it is prepared and reviewed for potential limited internal fixation, or lag screw fixation (Figs. 20.12, 20.13, 20.14, 20.15, 20.16, 20.17, 20.18, 20.19, and 20.20).



**Fig. 20.12** Lag screw across fracture osteotomy, pilot hole made with a 1.5-mm drill bit



**Fig. 20.13** Over-drill with 2.0-mm drill



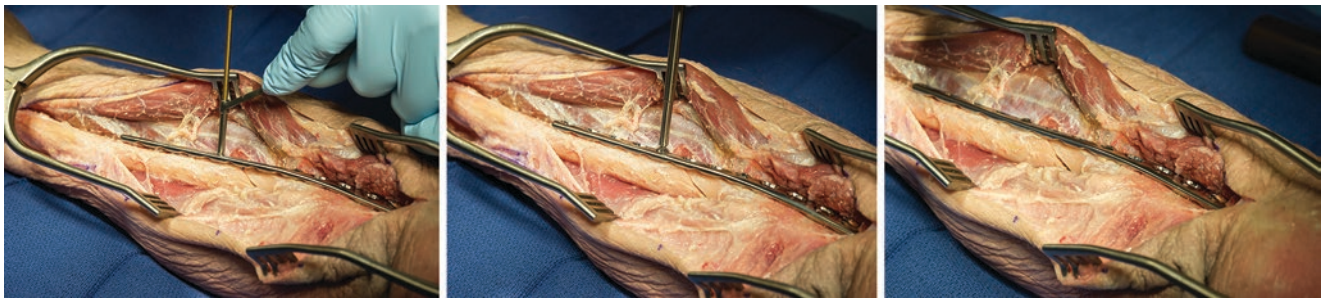
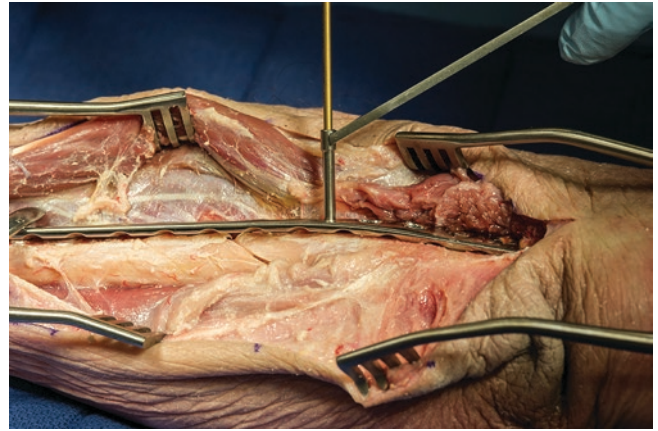
**Fig. 20.14** Countersink



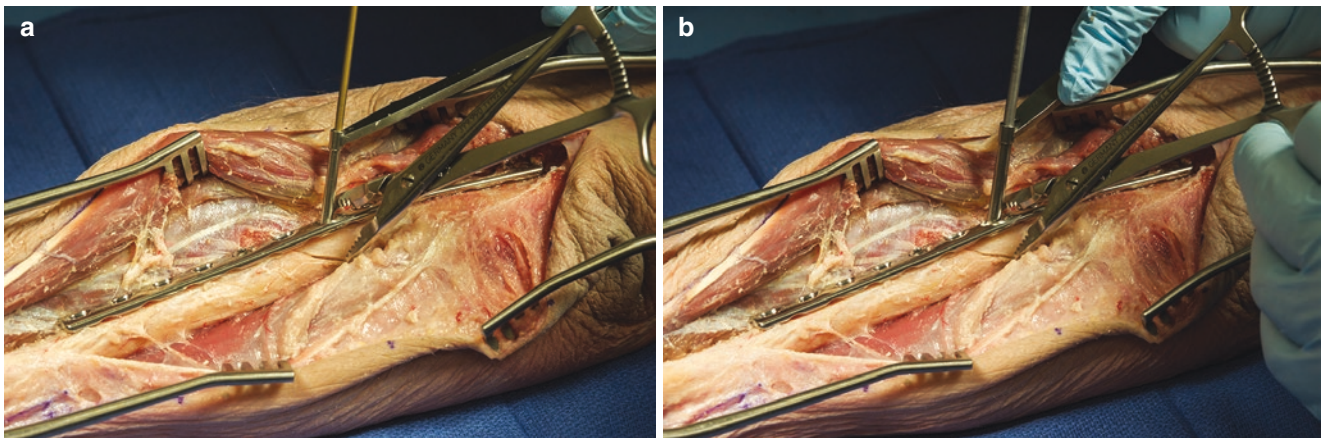
**Fig. 20.15** Measure, then inset screws



**Fig. 20.16** Plate fixation without lag screw first. The plate is positioned proximally first to ensure proper alignment. The screw will not be fully seated, as the distal screw will create the angle for compression



**Fig. 20.17** Distal screw insertion eccentrically drilled and seated will allow proximal screw tightening to generate compression

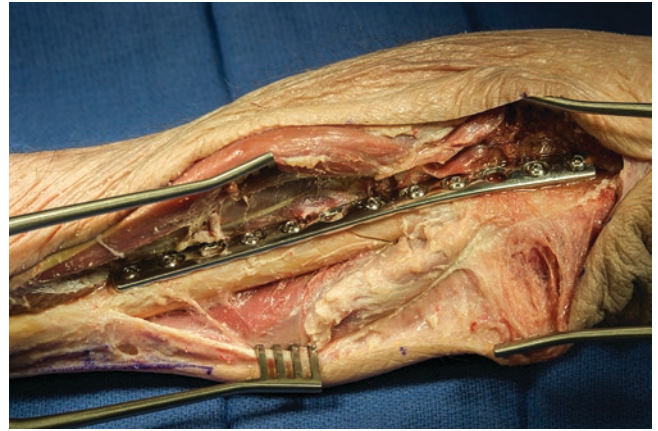


**Fig. 20.18** (a) Lag screw option through compression plate, as opposed to lag screw fixation prior to plating, beginning with 2.5-mm drill bit. (b) Over-drill with 3.5-mm drill bit





**Fig. 20.19** Screw insertion. I usually use a shaft screw for lags through plate



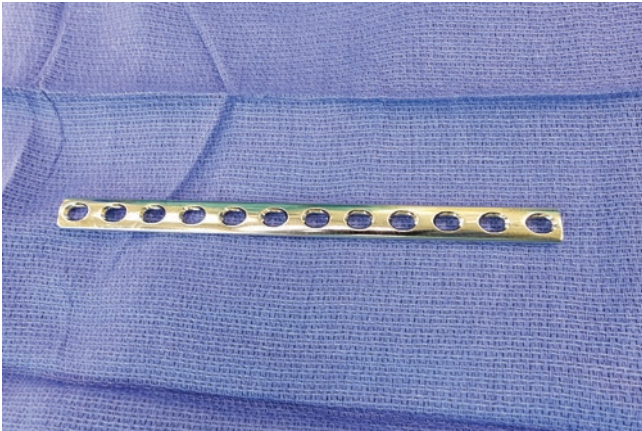
**Fig. 20.20** Final screws inserted in loaded fashion that is not neutral. But slightly eccentric to prevent distraction

If the fracture is transverse, then reduction and subsequent definitive plate fixation can be performed with a 3.5-

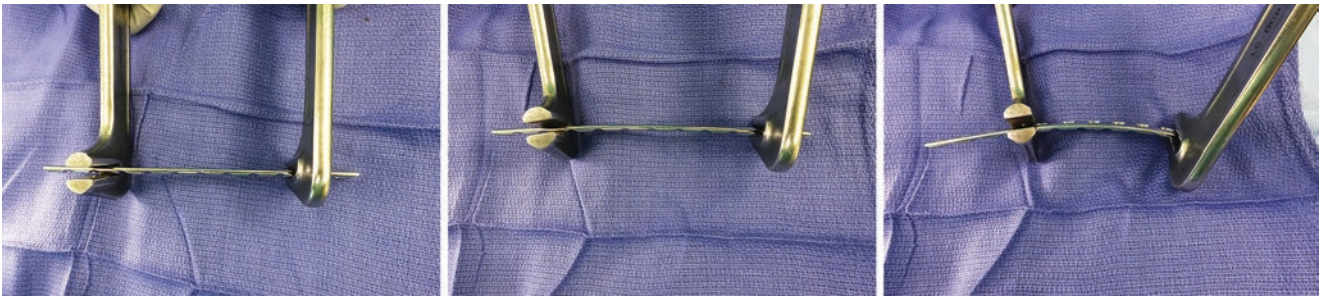
mm limited contact–dynamic compression plate (LC-DCP) (Figs. 20.21, 20.22, 20.23, 20.24, and 20.25).



**Fig. 20.21** Injury radiographs of Type II Monteggia of left forearm



**Fig. 20.22** 3.5-mm LC-DCP Synthes® plate



**Fig. 20.23** (a, b) Plate contouring with bending irons twist and bending at the same time



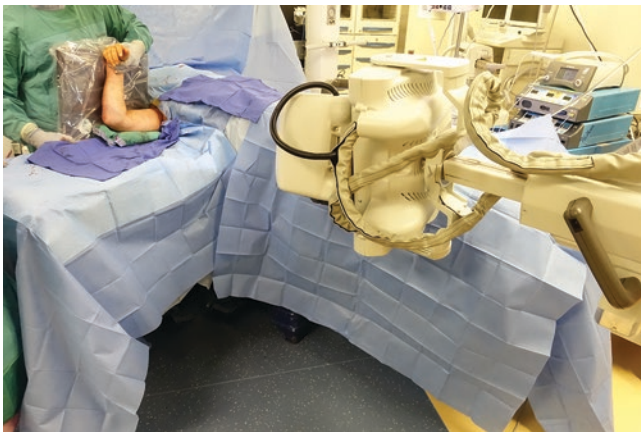
**Fig. 20.24** Final fixation. Note the medial antebrachial cutaneous nerve branch

**Fig. 20.25** Radiograph following open reduction internal fixation (ORIF) with closed reduction of radial head dislocation



Note that the reduction sometimes can be challenging, even when the radial head is not strangulated, incarcerated, or blocked from reduction. It is important to relax the patient by anesthesia. Once reduction and fixation is carried out, a

critical evaluation of the radiocapitellar joint is needed. Evaluation should be performed with the C-arm in a true lateral position, with the forearm in neutral pronation supination and the elbow at 90° flexion (Fig. 20.26).

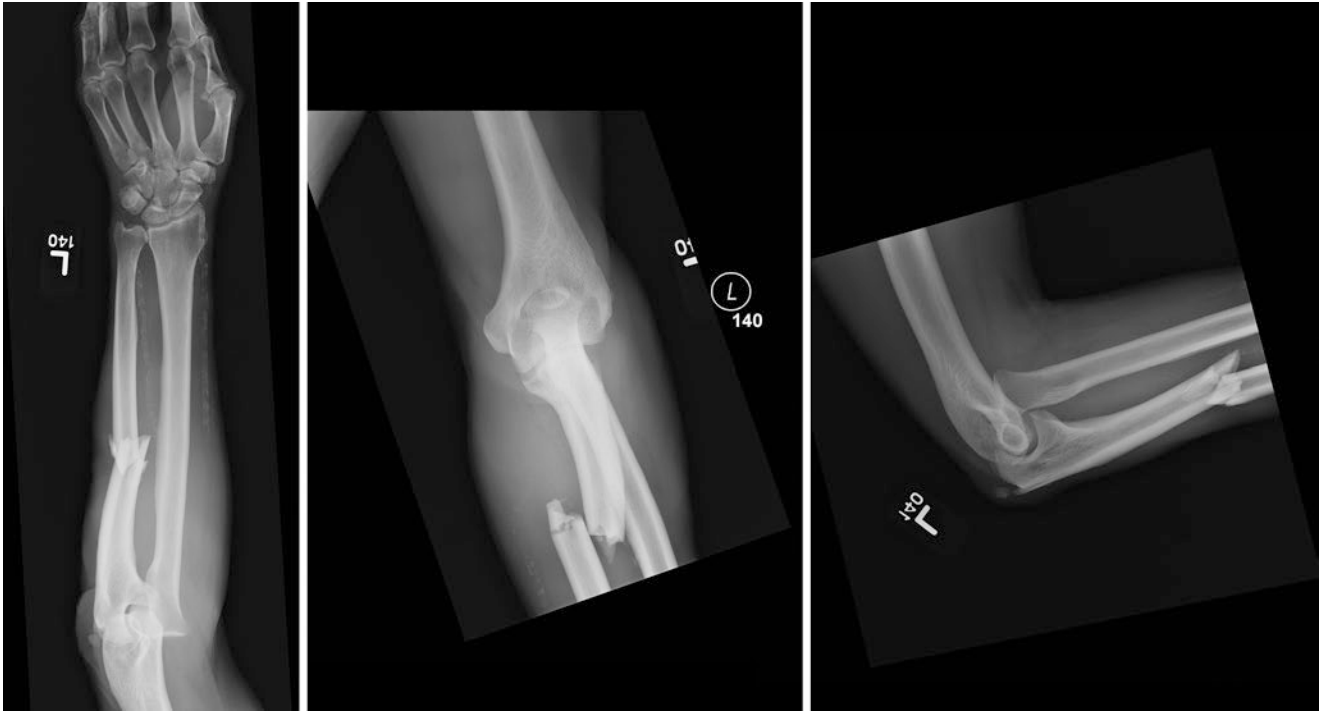


**Fig. 20.26** Arm positioned for lateral elbow radiograph



Passive range of motion should be performed to confirm adequate reduction. Radiographically, or under direct joint inspection, stability will guide the subsequent postoperative plan. If needed, I approach the radiocapitellar joint, either through a separate incision or by extending the ulnar incision more proximally, elevating the skin flap and going just anterior to the lateral collateral ligament complex. I prefer not to

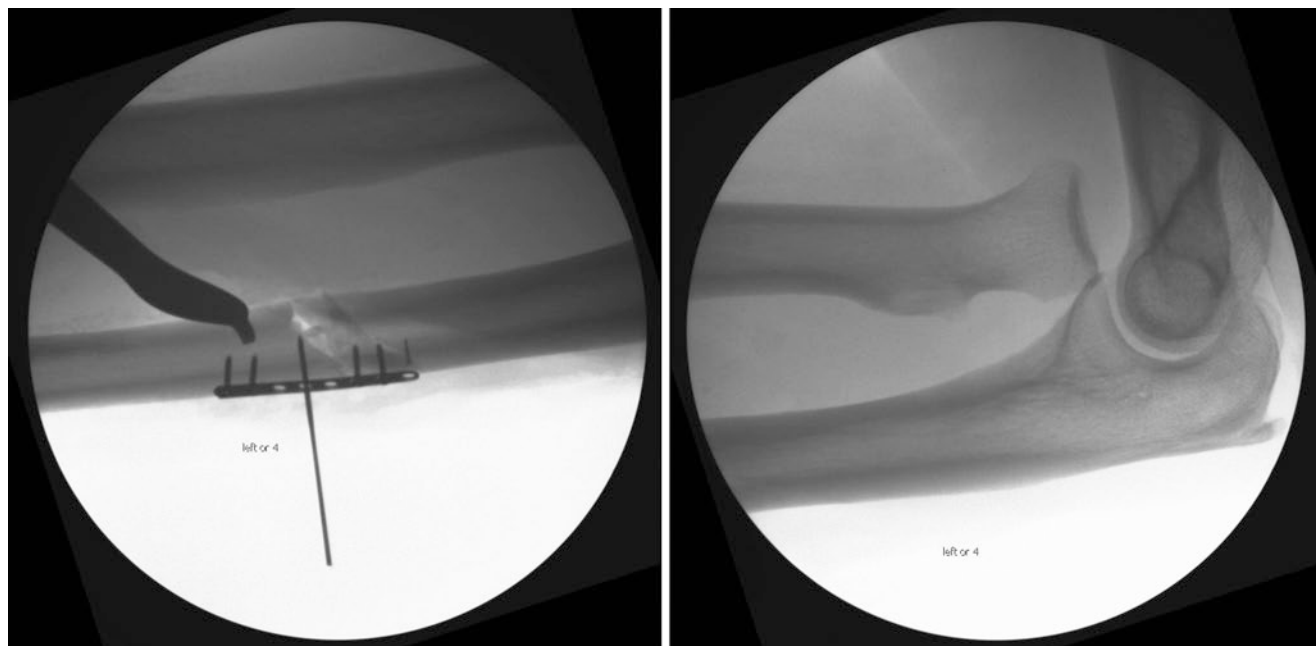
violate the posterior lateral aspect of the lateral ligamentous structures. When the annular ligament is pulled off as an intact sleeve interposed between the radial head and capitulum, Freer or Hohmann retractors can be used to deliver the annular ligament back around the radial head neck in a shoe-horn fashion (Figs. 20.27, 20.28, 20.29, 20.30, 20.31, 20.32, 20.33, and 20.34).



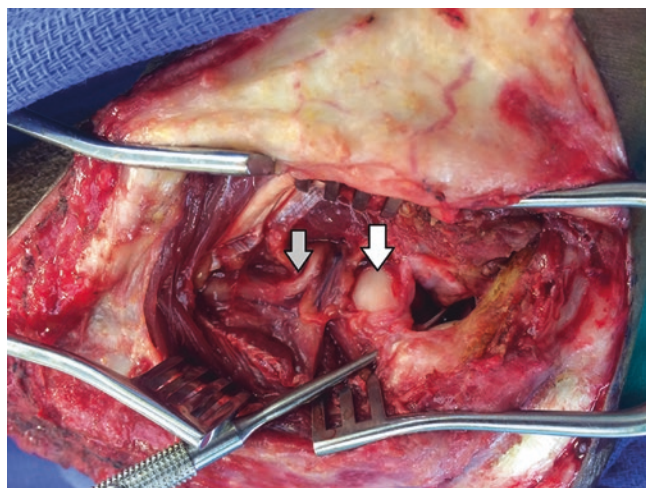
**Fig. 20.27** Forearm and elbow radiographs of Type I left Monteggia fracture



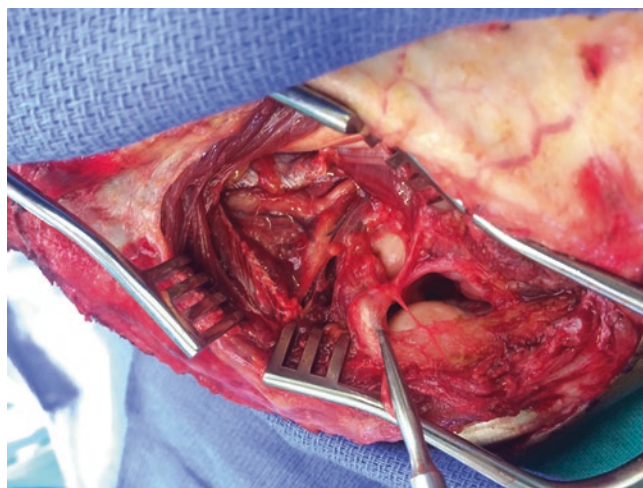
**Fig. 20.28** Reduction and provisional fixation of the ulna



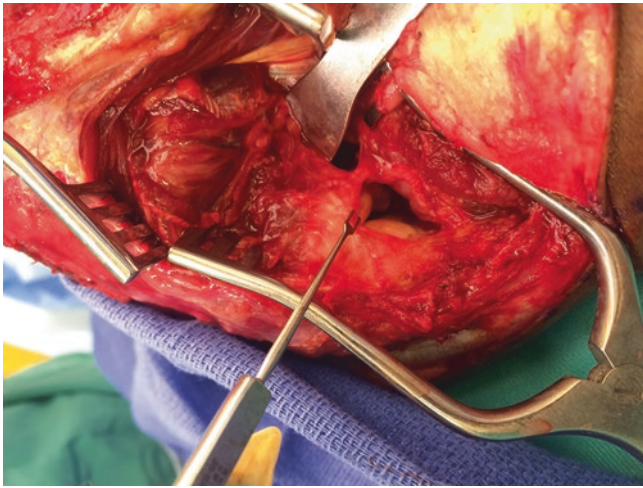
**Fig. 20.29** Intraoperative C-arm radiograph showing provisional reduction and fixation of the ulna with dislocated head



**Fig. 20.30** Anterolateral exposure with radial head (*white arrow*) anterior to capitellum with Freer elevator through annular ligament, posterior interosseous nerve (PIN) (*gray arrow*)



**Fig. 20.31** Annular ligament retracted, revealing capitellum and interposed capsule



**Fig. 20.32** Reduced radial head, with skin hooks retracting annular ligament



**Fig. 20.33** Lateral radiograph following open reduction of dislocated head



**Fig. 20.34** Intraoperative radiographs following ORIF with open reduction of radial head



### 20.5.1 Crista Supinatoris, Ligamentous Reconstruction

Occasionally the ligament is pulled off the crista supinatoris, which will require reinsertion with either transosseous sutures, suture anchors, or mini-fragment plates [17]. Rarely is a ligamentous reconstruction performed. If reconstruction is required, I have found that the technique of using a strip of triceps to reconstruct the annular ligament, as suggested by Bell Tawse [18], works nicely.

### 20.6 Postoperative Treatment, Patient Rehabilitation

Postoperatively, if the radial head is reduced with the reduction of the ulna, I treat the fracture as if it were essentially an isolated ulna fracture, allowing full range of motion, weight-bearing, and strengthening as tolerated. Generally, I apply a splint immediately after the operation; the splint is then removed on postoperative day one. If the radiocapitellar joint required direct visualization and surgical reduction, I limit the patient from unrestricted activities for approximately 4 weeks, awaiting ligamentous healing.

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## 21.1 Successful Treatment of Shaft Fractures

There is little controversy concerning the necessity of surgical intervention for skeletal realignment in radius and ulnar shaft fractures [1, 2]. Since the 1975 report by Anderson *et al.* [3] demonstrated high union rates with the use of 4.5-mm plates for open reduction internal fixation (ORIF) of radius and ulna shaft fractures, numerous authors have pre-

sented supportive results [4–9]. High union rates are reported following ORIF with various plates and varying numbers of screws (Table 21.1).

Open fractures have also been successfully treated both acutely and in a delayed fashion. In 1986, Moed *et al.* [10] reported the results of ORIF for 79 fractures in 50 patients, of which 38 were open fractures in 28 patients. Union was achieved in 91.4% (32/35) of the radius fractures and 90.9% (40/44) of ulna fractures. Acute bone grafts were used in 16 fractures.

**Table 21.1** Review of plating of closed radius and ulna fractures

Author	Year	Patients/Fractures, <i>n</i>	Plates	Cortices	Union rates
Anderson <i>et al.</i> [3]	1975	244/330 (28/38 open)	4.5-mm DCP	4–6	Overall: Radius 97.9% Ulna 96.3% Radius: No BG: 97.3% (146/149) BG: 97.8% (43/44) Ulna: No BG: 95.6% (87/91) BG: 97.8% (45/46) (BG performed for >1/3 comminution)
Dodge and Cady [4]	1972	78/119 (28 pts. both radius & ulna ORIF) Not all fx plated; some IM nails or nonoperative	Size not defined; 5–8-hole	–	Radius: 93% (26/28) Ulna: 100% (28/28)
Chapman <i>et al.</i> [5]	1989	87/129 49 (38%) open, immediate fixation IIIB/IIIC excluded	3.5-mm DCP: 117 fx 4.5-mm DCP: 3 fx Semitubular: 3 fx 1/3 tubular: 4 fx	5	Overall: 97% Radius: 100% Ulna: 97% BG: 68 fx
Leung and Chow [6]	2003	92/125	PC fixation (unicortical lock screws): 59 fx LC-DCP: 66 fx	Not stated	Radius: 100% (65 fx) Ulna: 100% (60 fx) Delayed: PC: 4 fx LC-DCP: 5 fx
Lindvall and Sagi [7]	2006	53/75	DCP	4	Radius: 97.1% (34 fx) Ulna: 97.6% (41 fx)

BG bone graft, DCP dynamic-compression plate, fx fractures, IM intramedullary, LC-DCP limited contact dynamic compression plate, ORIF open reduction internal fixation, PC point contact

## 21.2 Review of Fractures Treated at Shock Trauma

An unpublished Shock Trauma review (Widmaier JC, Eglseder WA, 1998) examined the timing of wound closure and bone grafting for open forearm fractures in 127 patients with 199 open fractures of the radius and ulna, who underwent ORIF due to nonpenetrating trauma. The fracture breakdown includes the number of patient cases by open fracture type:

- Type I: 48
- Type II: 46
- Type III-A: 17
- Type III-B: 11
- Type III-C: 5

This review included three observations:

- Fractures of Type I, Type II, and Type III-A may be primarily closed after ORIF without significant effect on the infection rate.
- Early flap closing (within 3 days) is recommended for Type III-B fractures.
- Early bone grafting (at the time of definitive wound closure) does not increase the infection rate.

### 21.2.1 Intramedullary Fixation

Intramedullary (IM) fixation is advocated; both radius and ulna fractures can be treated with IM fixation and with hybrid constructs. In such cases, notable advantages include a decreased refracture rate following fixation removal and decreased soft tissue disruption and dissection during insertion.

Table 21.2 reveals very successful union rates regardless of technique, and the functional results largely mirror the union rates. The bottom line is that union rates should be greater than 90% regardless of technique, type of plates, nails, or number of screws. The technique chosen is based on preference and emotion. Whether the soft tissue injury tends to drive your decision to nail, or an arterial injury, to use plates, you can use whatever is most comfortable to you according to the scenario.

My own experience with IM fixation has not been as positive as the reports demonstrate. This may reflect a failure on my part to ascend the up-slope of the learning curve. Because many of our patients have conditions that I feel require a more extensive exposure—open fractures and arterial or nerve injuries—I find that the opportunity to utilize the IM option is intermittent. Thus my approach and philosophy regarding radius and ulna shaft fractures is neither a sweeping exclusionary endorsement of ORIF nor a condemnation of IM fixation.

**Table 21.2** Review of intramedullary nailing of radius and ulna fractures

Author	Year	Patients/Fractures, <i>n</i>	Plates	Union rates
Behnke <i>et al.</i> [11]	2012	56/112	27 pts.: Plate radius & ulna 29 pts.: IM nail, radius; 3.5-mm DCP or LC-DCP, ulna	Radius: 96% (26/27) Ulna: 100% (27/27) <i>Plate (ulna) &amp; nail (radius):</i> Radius: 97% (28/29) Ulna: 100% (29/29)
Weckbach <i>et al.</i> [12]	2006	32/40 (29/36 follow-up)	Interlocking IM nail (some hybrid)	<i>IM nails only:</i> Radius: 93% (13/14) Ulna: 100% (20/20)
Lee <i>et al.</i> [13]	2008	27/38	Interlocking IM nail	Radius: 100% (18/18) Ulna: 95% (19/20)
Saka <i>et al.</i> [14]	2014	43/59	Interlocking IM nail	Radius & ulna: 100% (28) Radius 100% (14) Ulna: 100% (17)

DCP dynamic-compression plate, IM intramedullary, LC-DCP limited contact dynamic compression plate



### 21.2.2 Bone Grafting

Finally, the timing and the necessity of bone grafting were reviewed. Bone grafting was performed when fractures had more than one third cortical comminution, with healing rates similar to those of non-comminuted fractures [3], but a control group with greater than one-third comminution without bone grafting was not included in the report. The necessity of

bone grafting has been questioned and was evaluated by two other papers [15, 16] (Table 21.3).

I tend to use the following criterion: If there is any bony contact, I don't bone graft. In such cases, I acknowledge that the healing may occur with what I call an incompetent union, with a quantity of bone such that you would be reluctant to remove a plate.

**Table 21.3** Review of bone grafting in radius and ulna fractures

Author	Year	Patients/Fractures, <i>n</i>	Plates	Union rates
Wright <i>et al.</i> [15]	1997	137/183	3.5-mm DCP	<i>No bone graft:</i> Non-comminuted: 98% (52/53) Comminuted: 98% (99/101) Open, non-comminuted: 100% (11/11) Open, comminuted: 100% (24/24) <i>Bone graft:</i> Comminuted: 83% (24/29) Open, comminuted: 82% (18/22)
Wei <i>et al.</i> [16]	1999	49/64 ( $\geq 1$ y follow-up, 56 fx)	Not stated	Overall: 98% (55/56) <i>No bone graft:</i> Non-comminuted: 95% (19/20) Comminuted: 100% (25/25) <i>Bone graft:</i> Comminuted: 100% (11/11)

BG bone graft, DCP dynamic-compression plate, fx fractures

### 21.2.3 ORIF Sequence

All residents and fellows should remember the following sequence as a mantra as they perform ORIF:

1. Expose radius.
2. Expose ulna.
3. Fix radius.
4. Fix ulna.
5. Close ulna.
6. Close radius.

This sequence is driven by the importance of the particular bone as well as the particular scenario. At Shock Trauma, our procedures are sometimes rapid, with limited

surgical time, because of the patient's overall status. I like to expose the radius and then expose the ulna, as opposed to exposing one and fixing it, because occasionally the soft tissues block the reduction. In such cases, manipulation is required to disengage the fracture from incarcerated muscle, and this procedure is facilitated by having both bony structures exposed.

I prefer to stabilize the radius first because the patient will be in the supine position, which allows the arm to be nicely supinated without anyone holding it. Once the radius is at least provisionally stabilized by flexing the elbow, there is no need for someone to hold the arm up in the air, even if the ulna has a simpler fracture pattern. Also, if the patient may be hemodynamically unstable, I like to have at least the radius stabilized, rather than the ulna (Figs. 21.1, 21.2, and 21.3).

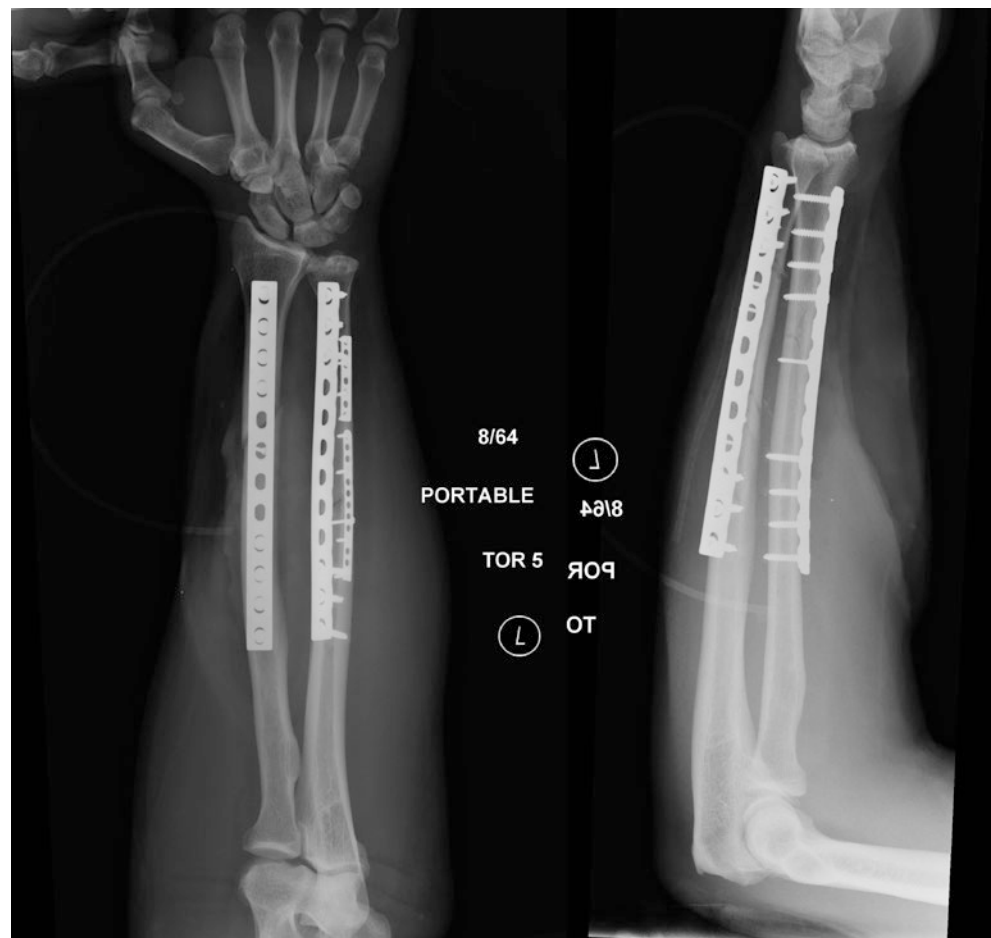
**Fig. 21.1** Injury radiograph of open left radius and ulna fracture in a hemodynamically unstable patient (the only view obtained)



**Fig. 21.2** Limited internal fixation following debridement during multiple staged procedures



**Fig. 21.3** Definitive fixation performed in a delayed fashion



Soft tissue tensioning will actually facilitate some of the ulna reduction once the radius is stabilized. I close the ulna first because the subcutaneous border does not lend itself well to a delayed closure, and I prefer full-thickness

coverage over the tendons and plate. Finally, if skin grafting would be required, the forearm bed anteriorly is much more amenable to skin grafting than the dorsal ulnar surface.



## 21.3 Surgical Techniques

### 21.3.1 Patient Prepping and Draping

The setup, prepping, and draping sequence demonstrated in Figs. 21.4, 21.5, 21.6, 21.7, 21.8, 21.9, 21.10, 21.11, 21.12, 21.13, and 21.14 utilizes a nonsterile tourniquet. The same patient setup is applied in Chaps. 23–28.

**Fig. 21.4** Hand table centered on shoulder



**Fig. 21.5** Patient positioned with 6-inch padding and nonsterile tourniquet, tourniquet tubing under table, arm suspended from ceiling support



**Fig. 21.6** Padding cut and turned down to prevent tourniquet translation



**Fig. 21.7** Impervious drape around tourniquet and padding



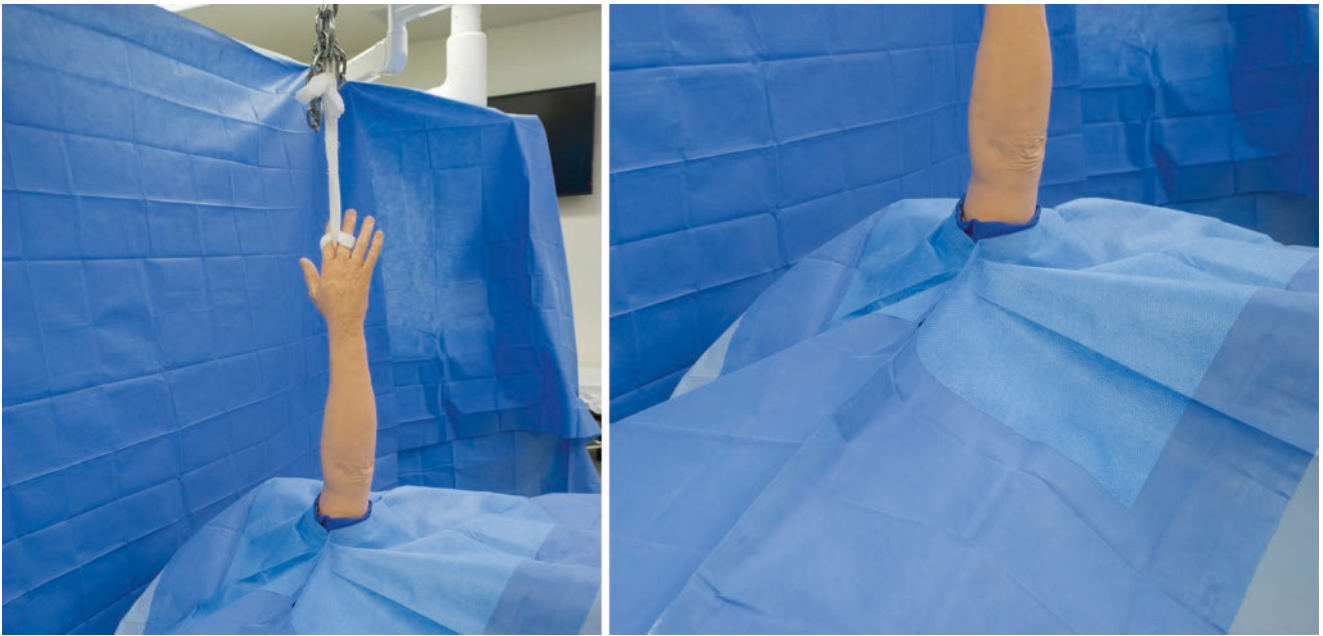
**Fig. 21.8** Absorbent drape cut out around arm; after prepping, drapes are removed



**Fig. 21.9** Body drape stopping at bottom of hand table



**Fig. 21.10** Roll towel around tourniquet, kept high



**Fig. 21.11** Split drape with tails down, kissed together



**Fig. 21.12** Kelly clamp used to slide suspension sling over finger



**Fig. 21.13** Fingers painted with sterile prep solution



**Fig. 21.14** Split drape with tails up, followed by blue towel under arm



### 21.3.2 Intraoperative Radiographs

Figures 21.15, 21.16, 21.17, 21.18, and 21.19 illustrate various positions for obtaining anteroposterior (AP) and lateral radiographs. Obtaining radiographs intraoperatively needs to be reinforced, as fixation adjustment is difficult to do after closure, dressings, and splinting, or in the recovery room.



**Fig. 21.15** Anteroposterior (AP) radiographs with marking towel with sterile saline to assist in cropping the film



**Fig. 21.16** AP radiograph with arm maintained in supination



**Fig. 21.17** Lateral radiograph: cross-table lateral with three-quarter drape over body

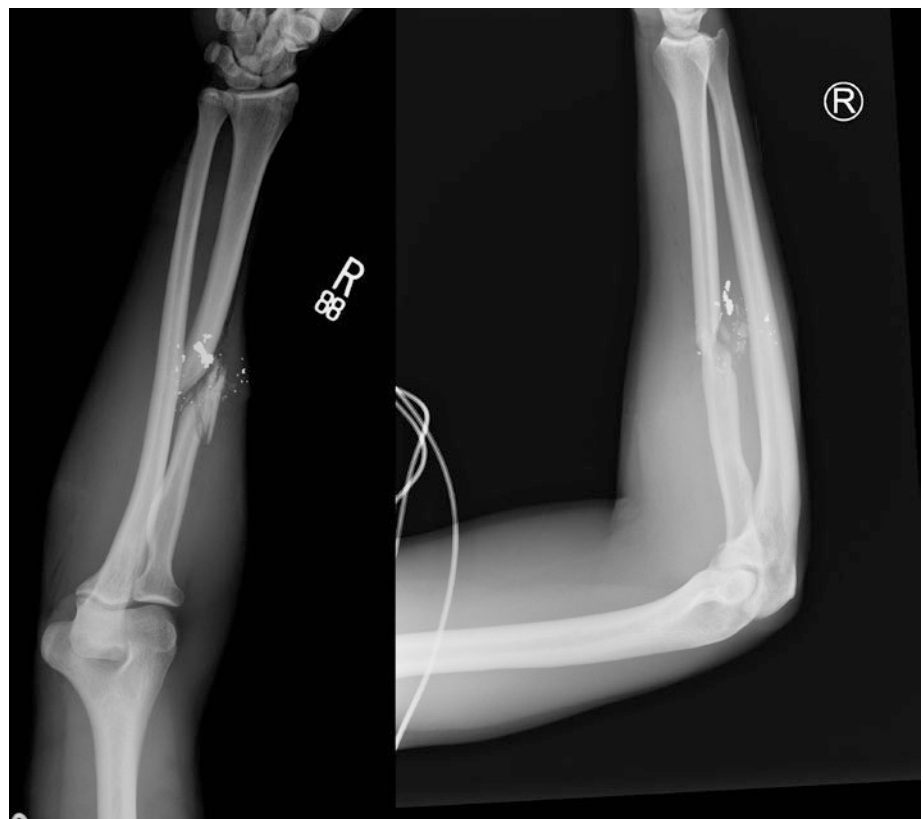


**Fig. 21.18** Cassette turned 90 degrees, not rotating the arm; pronating the arm after the initial AP radiograph will give the same view of the ulna

**Fig. 21.19** Radiograph of left forearm performed by pronation and supination, resulting in same projection of ulna as opposed to positioning the cassette at orthogonal position with arm in one position to get true AP/lateral radiographs

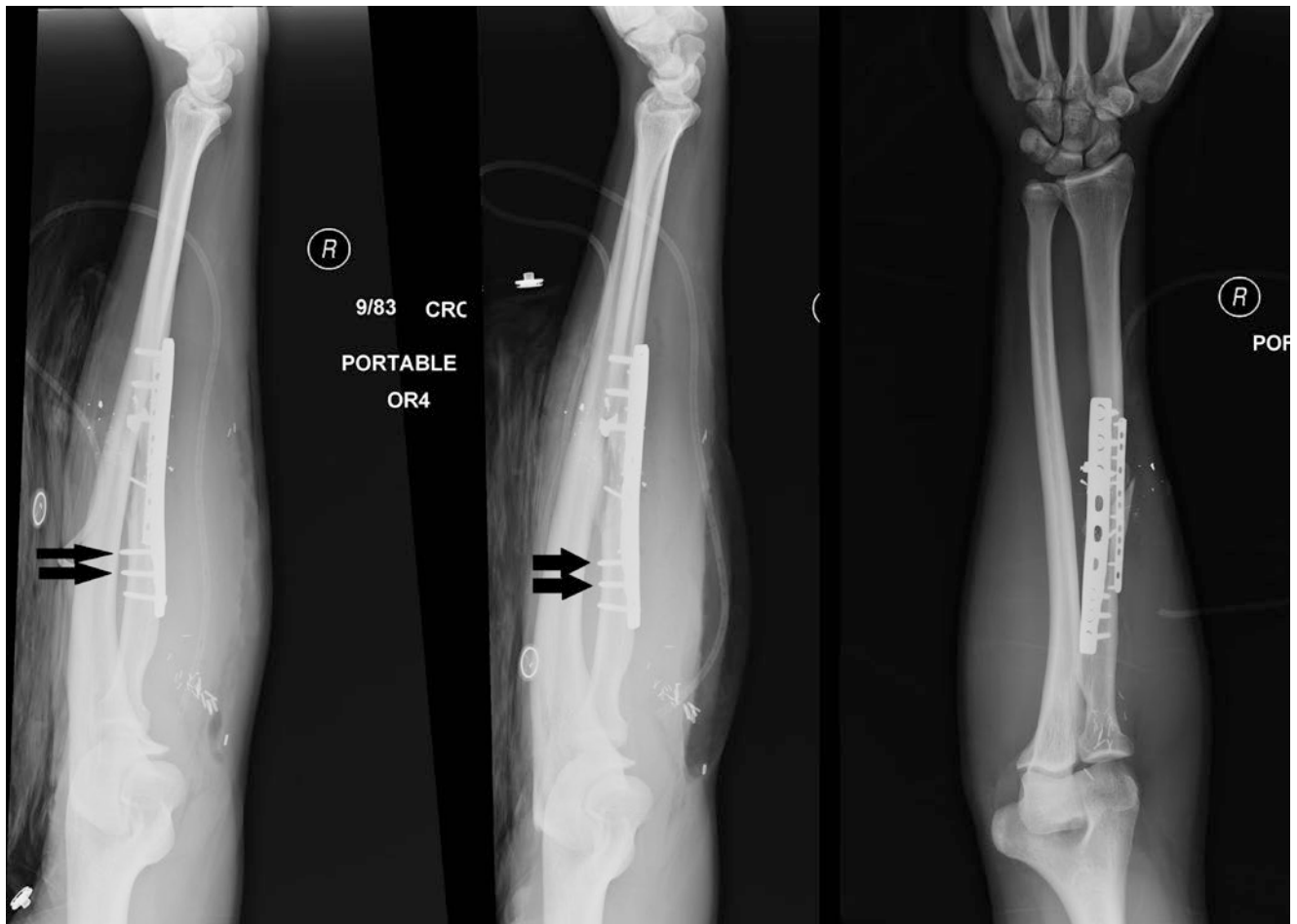


The case shown in Figs. 21.20 and 21.21 illustrates screw adjustment that, if left prominent, could have impacted the posterior interosseous nerve.



**Fig. 21.20** Injury radiographs of right radial shaft fracture





**Fig. 21.21** Intraoperative radiographs demonstrating prominent screws (*arrows*) and possible risk to posterior interosseous nerve corrected prior to closure

### 21.3.3 Operative Approaches

I approach the radius anteriorly from proximal to distal, exclusive of intraarticular fractures (Figs. 21.22 and 21.23).

**Fig. 21.22** Injury radiographs of segmental right radius and ulna shaft fractures



**Fig. 21.23** Radiographs following open reduction and internal fixation (ORIF) from radial head to distal watershed through an anterior approach



I believe that the radial head and the intraarticular distal radius should be approached dorsally. I have never been an advocate of the Thompson, or Boyd-Thompson, proximal dorsal approach because of the difficulties in extending the incision and the complications I've seen consequent to this approach. The innervation of the extensor digitorum communis (EDC), particularly the long ring fingers, occurs almost immediately after exiting the supinator [17]. Either because of tensioning the nerves or transecting them during the approach,

denervation may occur, though a multicenter study has failed to show any difference in complications utilizing either a Henry or Thompson approach [18]. The anterior flat surface of the radius affords a very nice plating surface, except for the more proximal surface where the plate would need to be curved around laterally to avoid impingement of the biceps tendon. The wrist fusion plate has been utilized for proximal fixation in an effort to minimize biceps tendon impingement (Higgins TF, Eglseder WA, 2000 (unpublished) (Figs. 21.24 and 21.25).

**Fig. 21.24** Injury radiographs demonstrating right proximal radius and ulna shaft fractures



**Fig. 21.25** Radiographs following ORIF, including a wrist fusion plate on the radius



Recessing into the neck and head can also be performed (Figs. 21.26, 21.27, 21.28, and 21.29).

**Fig. 21.26** Injury radiograph with right proximal radius fracture





**Fig. 21.27** ORIF with endosteal plates for provisional fixation and recessed plate on radial head and neck, performed through an anterior approach



**Fig. 21.28** Injury radiographs of right proximal radius fracture

**Fig. 21.29** Radiographs following ORIF that began with 1.5-mm mini-fragment plate, with contouring of radial tuberosity to allow recessing of the plate to avoid impingement on the biceps tendon



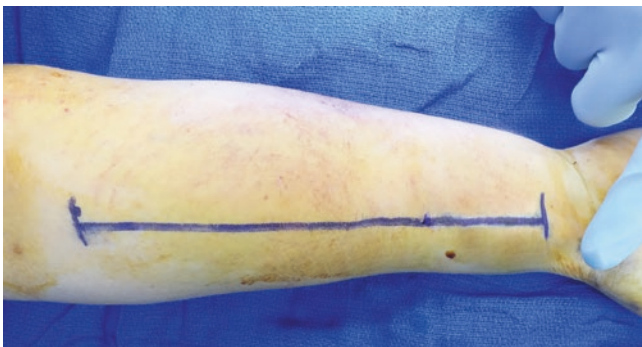


### 21.3.4 Open Fractures and Open Wounds

The skin incision is an anterior incision approximately from the radial head to the radial styloid, in the interval between the brachioradialis and the flexor carpi radialis (FCR). With open fractures, the question “What do I do with the open wound?” frequently arises. If the wound can be incorporated in the incision or veered slightly one way or the other, I will incorporate

the smaller open punctures with the incision. If the smaller open wound does not afford the opportunity for inclusion into the incision, I will use the “standard” incision, ellipse the open wound, and do the main debridement via the surgical approach (Figs. 21.30, 21.31, and 21.32). Larger defects will frequently require novel approaches in efforts to minimize soft tissue ramifications. Following the surgical incision marking, the tourniquet is inflated and the incision is carried out.

**Fig. 21.30** Injury radiographs of right radius and ulna shaft fractures



**Fig. 21.31** Incision for radial shaft exposure



**Fig. 21.32** Incision for ulna shifted to incorporate open wound

### 21.3.5 Nerves, Veins, and Arteries

The first structures of importance to be aware of are the cephalic vein and the lateral antebrachio-cutaneous (LABC) nerve. It is very important to respect the LABC nerve

(Figs. 21.33, 21.34, 21.35, and 21.36). It is frequently said that the dorsal sensory nerve of the radial nerve is encountered first in this area, but the dorsal sensory nerve does not even pierce the deeper structures between the brachioradialis and extensor carpi radialis longus until 8 cm proximal to the radial styloid.



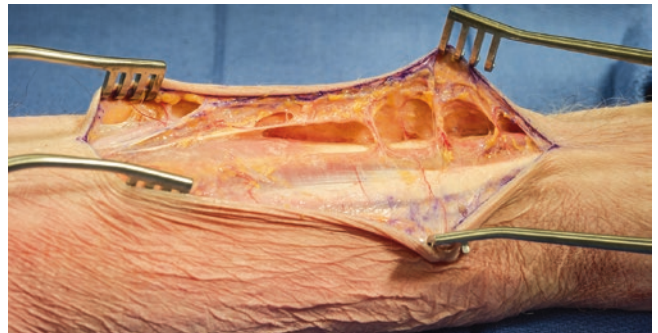
**Fig. 21.33** Anterior incision for radial shaft fracture with superficial landmarks of radial head to radial aspect of flexor carpi radialis



**Fig. 21.34** Dissection down to fascia over flexor carpi radialis with cephalic vein and lateral antebrachio-cutaneous (LABC) nerve



**Fig. 21.35** Blue background behind cephalic vein and LABC nerve

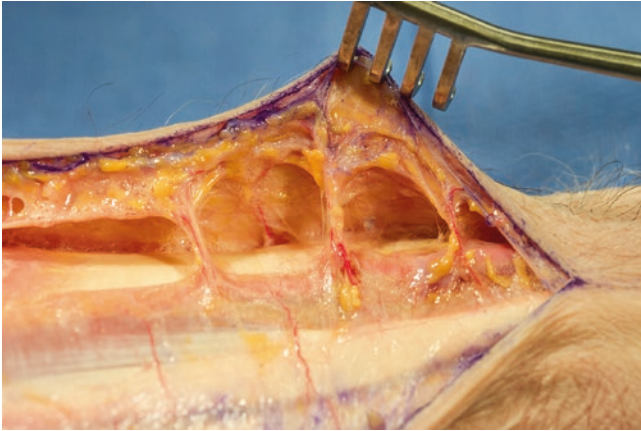


**Fig. 21.36** LABC nerve coursing into the radial skin flap (not the radial dorsal sensory nerve), along with perforators from the radial artery into the radial skin flap

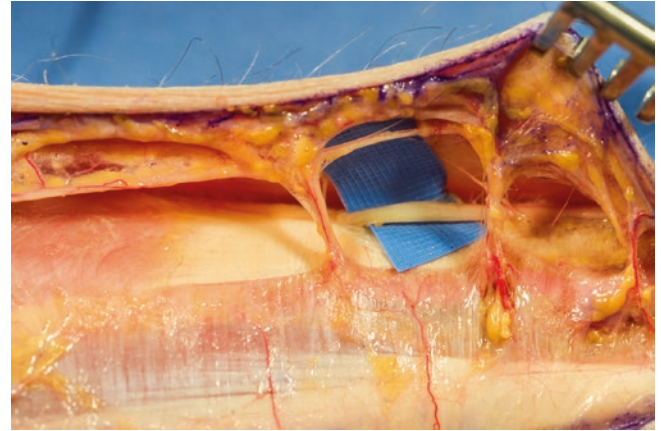


Occasionally, some small branches of the LABC that course ulnarly may need to be sacrificed, but in most cases, the LABC is retracted radially. The key to the approach is the brachioradialis, which will guide you to the dorsal sensory nerve as well as to the radial artery. The brachioradialis is a flat tendon with a triangular shape and

a flame-shaped muscle; it is located mid-forearm. The radial artery is generally identified distally and dissected along its radial aspect. The interval between the FCR and the brachioradialis is developed by dividing the fascia and retracting the brachioradialis radially (Figs. 21.37, 21.38, 21.39, and 21.40).



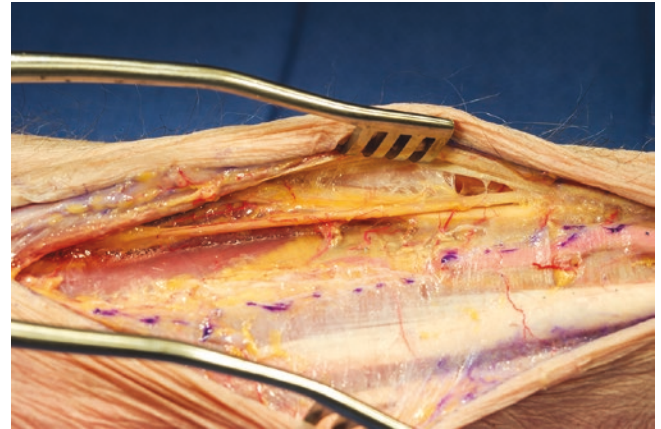
**Fig. 21.37** Cutaneous perforators from the radial artery



**Fig. 21.38** Background beneath superficial branch of the radial nerve (SBRN) exiting between the brachioradialis and extensor carpi radialis longus, 8 cm proximal to the radial styloid



**Fig. 21.39** Incision between the brachioradialis (BR) and the flexor carpi radialis (FCR)

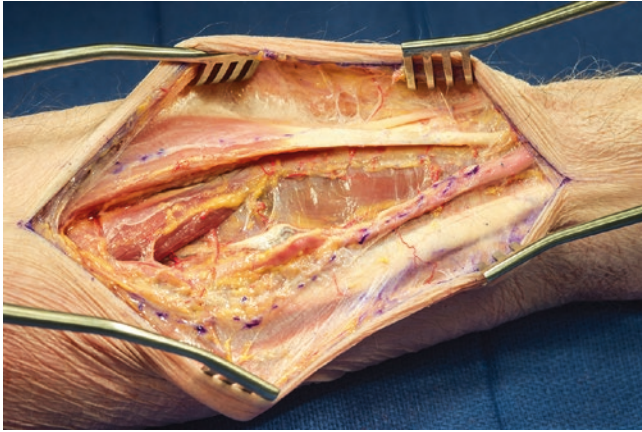


**Fig. 21.40** Plane developed between BR radially and pronator teres (PT) and FCR ulnarly; the SBRN is beneath the BR



I do not circumferentially dissect the radial artery; there is no need to skeletonize it. Preserving the attachments ulnarly with retraction of the FCR, the radial artery is retracted with the flexor pronators protecting it, which minimizes the potential for inadvertent injury and spasm if too much dissection is performed. I do not put Penrose drains or vessel loops around arteries and nerves with any dissection, as I think doing so is problematic and actually insults the artery or the nerve. The interval between the radial artery and the dorsal sensory nerve

is maintained. Continuing proximally, the brachioradialis is further dissected away from the pronator teres. If you are dealing with a proximal radial fracture, the radial recurrent vessels require division after Ligaclip® application. I believe this is one of the reasons for reluctance to use this approach proximally. The dissection required causes concern over potential injury to the radial artery. Once the plane has been developed between the radial artery and the brachioradialis, the pronator teres will be visualized (Figs. 21.41 and 21.42).



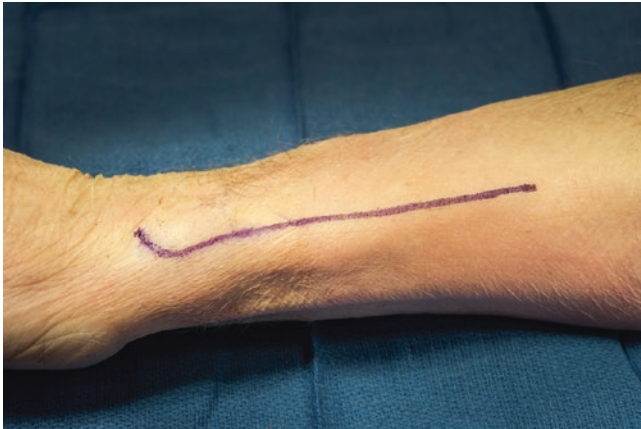
**Fig. 21.41** Deeper dissection with PT insertion preserved on the radius and the radial artery retracted ulnarly without dissection on the ulnar side of the artery. Do not skeletonize the artery



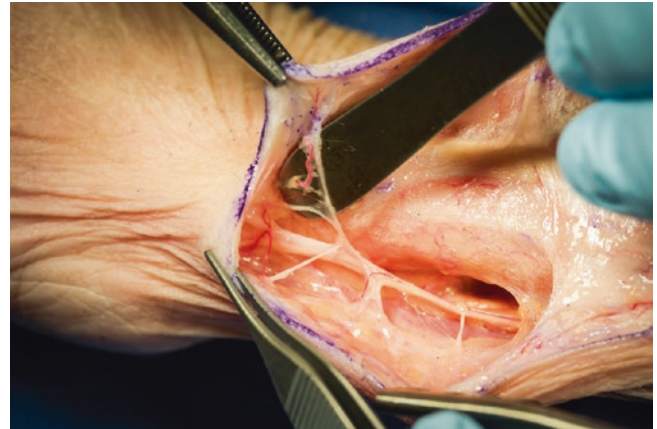
**Fig. 21.42** Innervation of the flexor pollicis longus by the anterior interosseous nerve

With the radius approached, the elbow is now flexed. Traction is required on the arm to prevent telescoping and secondary injury. A dorsal ulnar incision is utilized, not directly on the subcutaneous border of the ulna. The fascia is divided over the extensor carpi ulnaris (ECU). Just

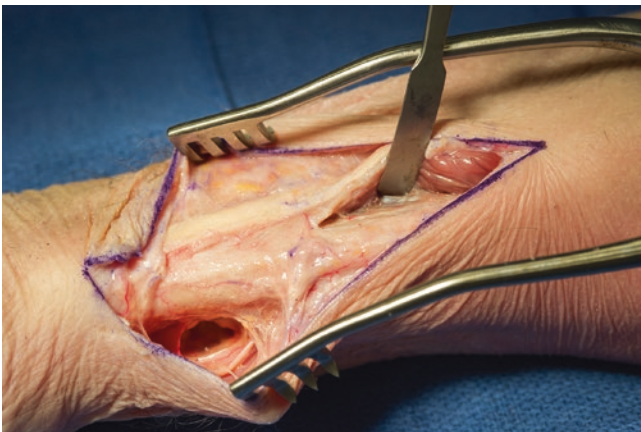
as the brachioradialis is the key to the forearm anteriorly, the ECU is the key to the forearm approach dorsally. Very rarely do I elevate the flexor carpi ulnaris (FCU), unless the fracture requires it (Figs. 21.43, 21.44, 21.45, and 21.46).



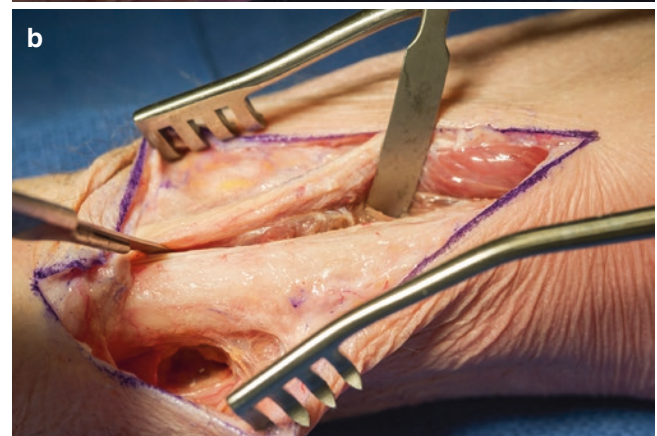
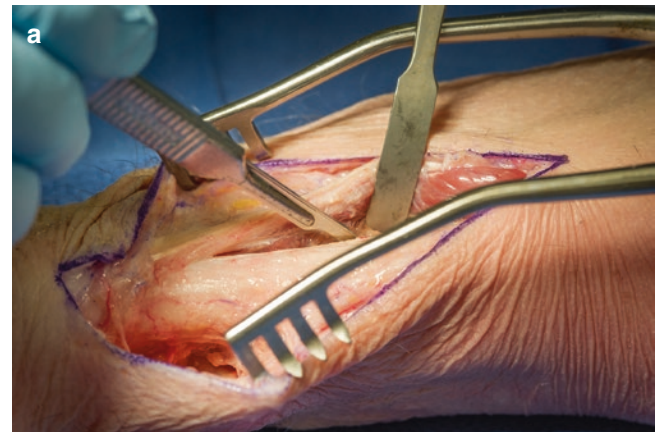
**Fig. 21.43** Incision for approach to distal ulna shaft and neck dorsoul-  
nar along the subcutaneous border. The incision curves dorsally over  
the ulnar head



**Fig. 21.44** Dorsal ulnar sensory nerve with branch that crosses over  
the ulnar head



**Fig. 21.45** Retraction beneath the extensor carpi ulnaris (ECU), which  
is the key to the approach to the ulna



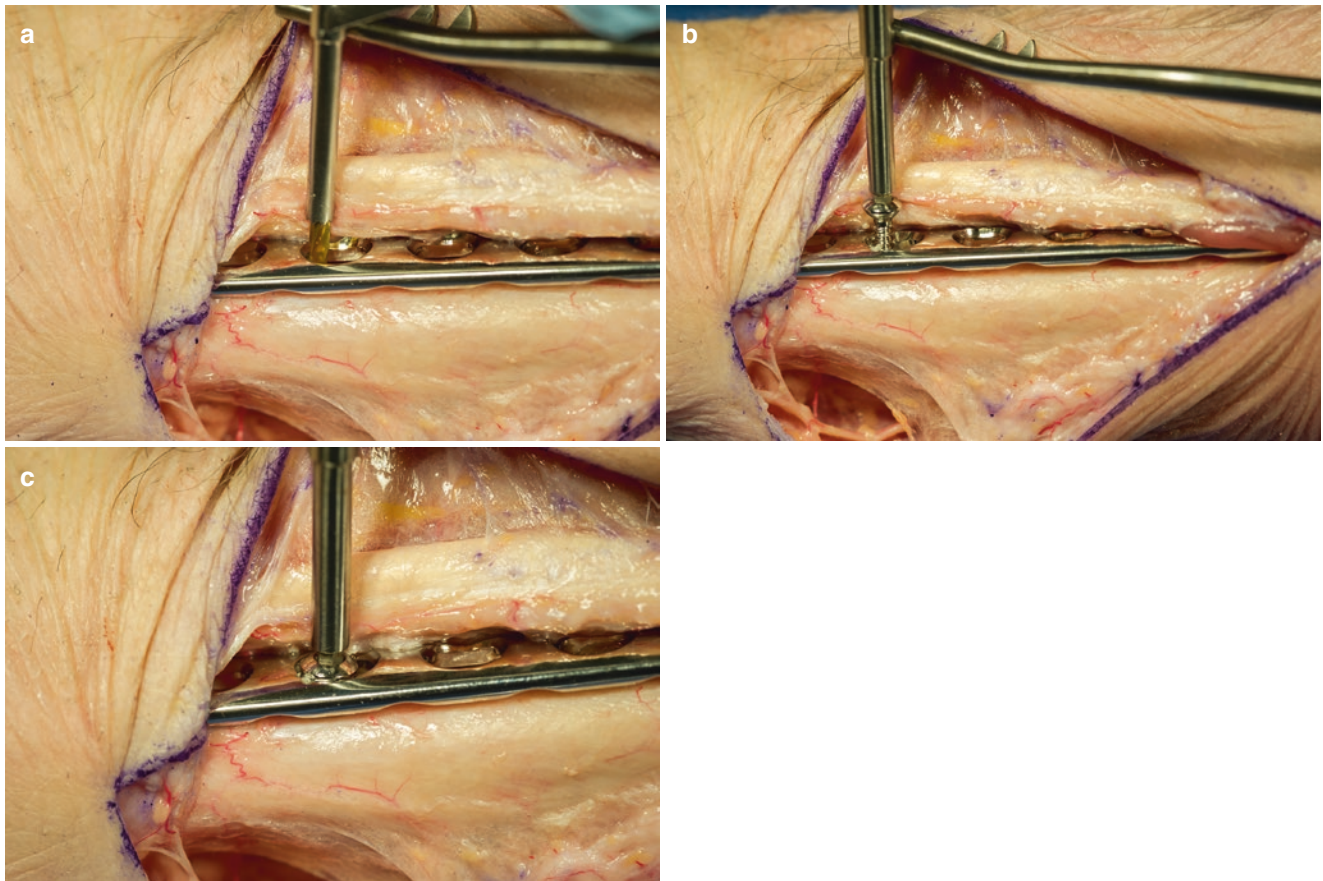
**Fig. 21.46** (a, b) Retraction of the ECU allows elevation with the  
knife in an extraperiosteal fashion



### 21.3.6 Preserving the Retinaculum

I also try to preserve the retinaculum distally, over the ulna head, acknowledging that there are two retinaculums to the sixth compartment. One is the subsheath across the ECU sulcus in the distal ulna. The other retinaculum comes around

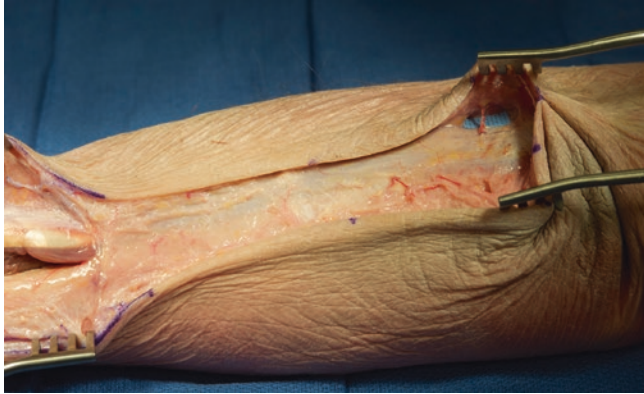
and inserts onto the pisiform. Occasionally, if the fracture is distal, I slide the plate beneath the retinaculum. The plating would be sub-ECU. A technique to get the plate beneath the ECU without dividing or limiting the distal exposure is to drive the plate distal with a screw placed in a distracting mode (Fig. 21.47).



**Fig. 21.47** (a–c) The plate may be positioned more distally with an eccentric screw placed distal before a compression screw is placed proximally



With the fascia divided distally (and this is where I generally start the approach), the ECU tendon can then be retracted; there is usually a very nice areolar plane allowing an extra-periosteal dissection from distal to proximal, which allows the plane to be developed in the mid-forearm. Occasionally,



**Fig. 21.48** Incision carried proximally for proximal shaft fractures. Note the background beneath the perforator to the skin from the radial recurrent vessels

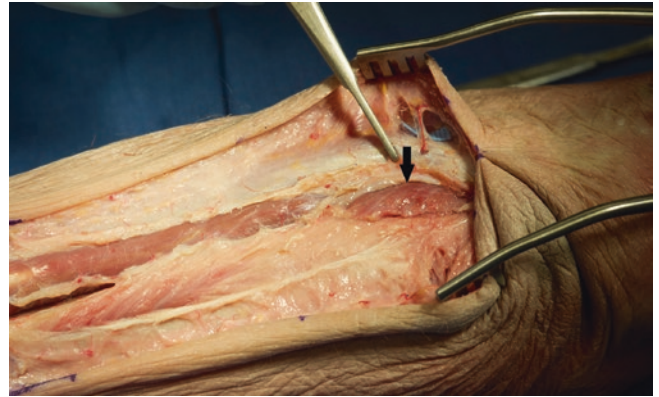
there is interdigitation between the FCU and the ECU. By developing a plane proximal between the anconeus and the FCU, the interval is defined. Continued proximally, occasionally the anconeus needs to be elevated, depending on the level of the fracture (Figs. 21.48, 21.49, 21.50, and 21.51).



**Fig. 21.49** Fascia incised and ECU elevated



**Fig. 21.50** Flexor carpi ulnaris (FCU) fibers blending into the ECU, making interval development difficult



**Fig. 21.51** Dissecting proximally to identify and elevate the anconeus (arrow) facilitates interval acquisition

With the ulna fracture now exposed, the radius is approached again. Final preparation of the fracture is carried out. The next rule of thumb is that if the fracture is in the distal half of the forearm, the pronator teres remains inserted and the dissection is between the flexor digitorum superficialis (FDS) and the pronator teres. If the fracture is in the proximal half, the pronator teres is elevated off from proximal to distal. The plane between the pronator teres and the supinator is frequently well defined and continued proximally, elevating the leading anterior edge of the supinator. There will be a bursa at the biceps tendon, allowing identification of the plane. This dissection can actually be carried up to the radial neck, and if necessary,

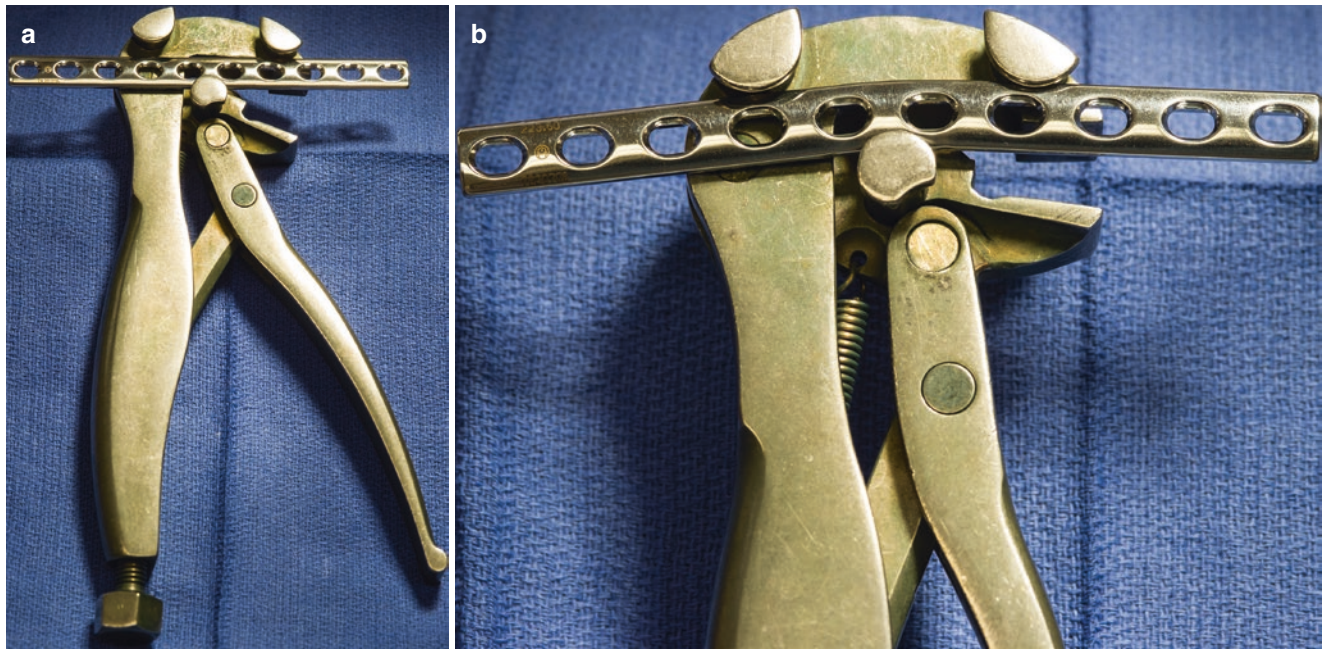
the leading edge of the annular ligament can be divided. Distally, the FDS, the flexor pollicis longus, and the pronator quadratus can be elevated to give access from the distal aspect of the radius, the watershed area of the distal radius.

A common mistake in visualizing the radial shaft is to be dissecting dorsally when, in fact, the elevation needs to be anterior. A nutrient vessel occurs in the proximal third of the radius, and, if possible, I try to preserve it. Occasionally the posterior interosseous nerve can be seen through the fibers of the supinator and in open fractures because of traumatic stripping, which is not uncommon. Therefore, I do not hesitate to identify the nerve.

## 21.4 Fixation Techniques

The fixation sequence is driven by the fracture configuration. In a relatively transverse fracture with interdigitation, reduction followed by definitive plating without provisional fixation

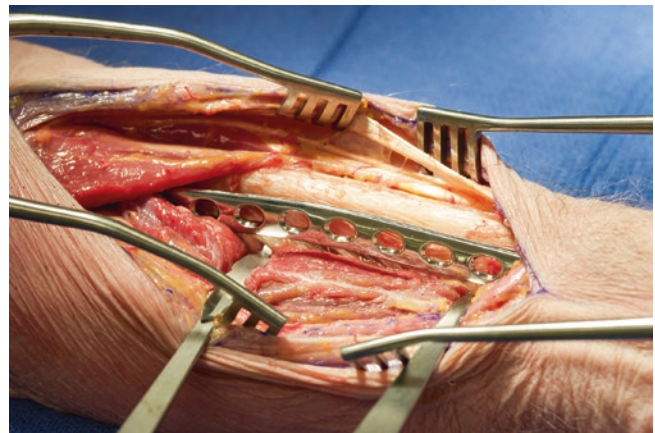
will usually suffice. Simple oblique fractures may be addressed with lag screws or a mini-fragment plate (including endosteal plates as seen in Fig. 21.29a) (Figs. 21.52, 21.53, 21.54, 21.55, 21.56, 21.57, 21.58, 21.59, 21.60, 21.61, 21.62, 21.63, 21.64, 21.65, 21.66, 21.67, 21.68, 21.69, 21.70, 21.71, and 21.72).



**Fig. 21.52** (a, b) Bending of plate in coronal plane for radial bow

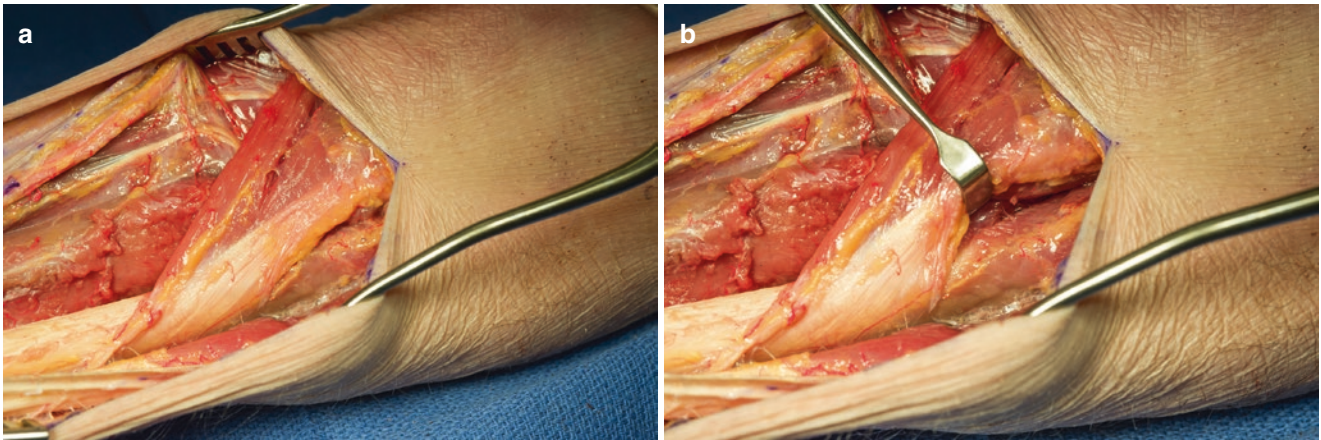


**Fig. 21.53** Acute bend in plate for press stress

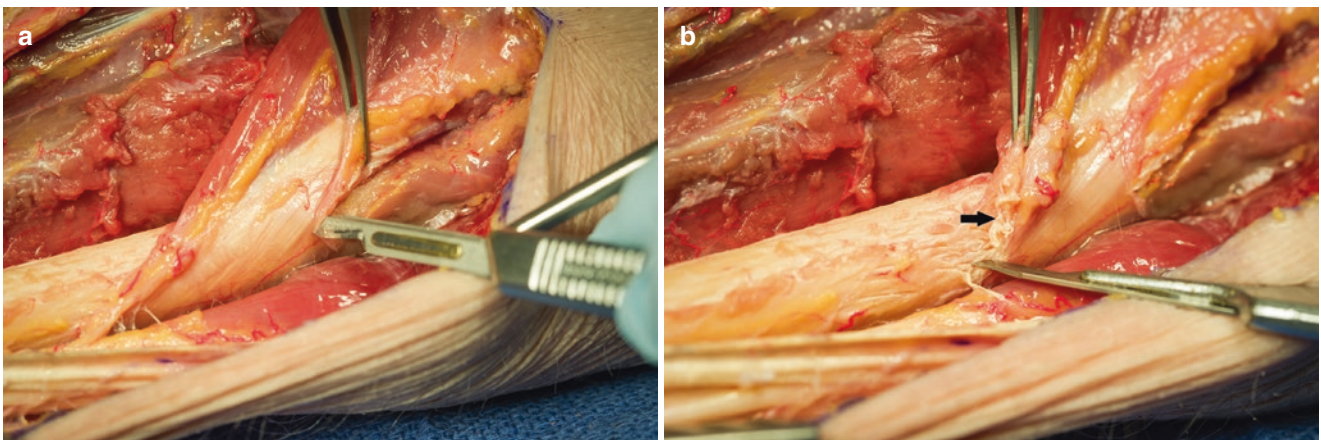


**Fig. 21.54** Positioning of plate for radial shaft fractures in distal half with PT insertion maintained





**Fig. 21.55** (a, b) Preparation of PT elevation for proximal-half fractures of the radius with an interval developed proximally between the PT and supinator

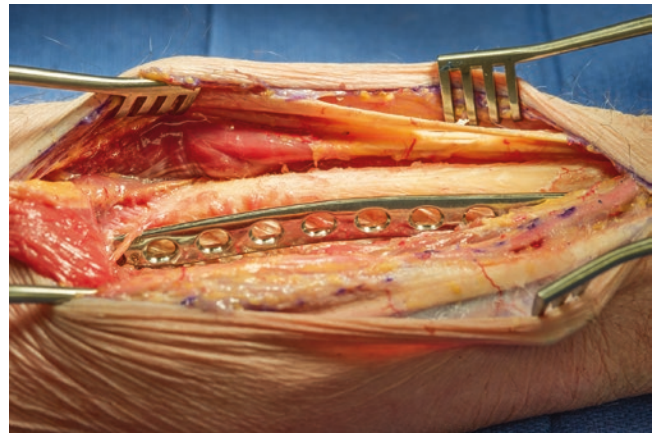


**Fig. 21.56** (a, b) Elevate the PT in the acute angle proximal to distal, to prevent feathering of the PT if it is elevated distal to proximal





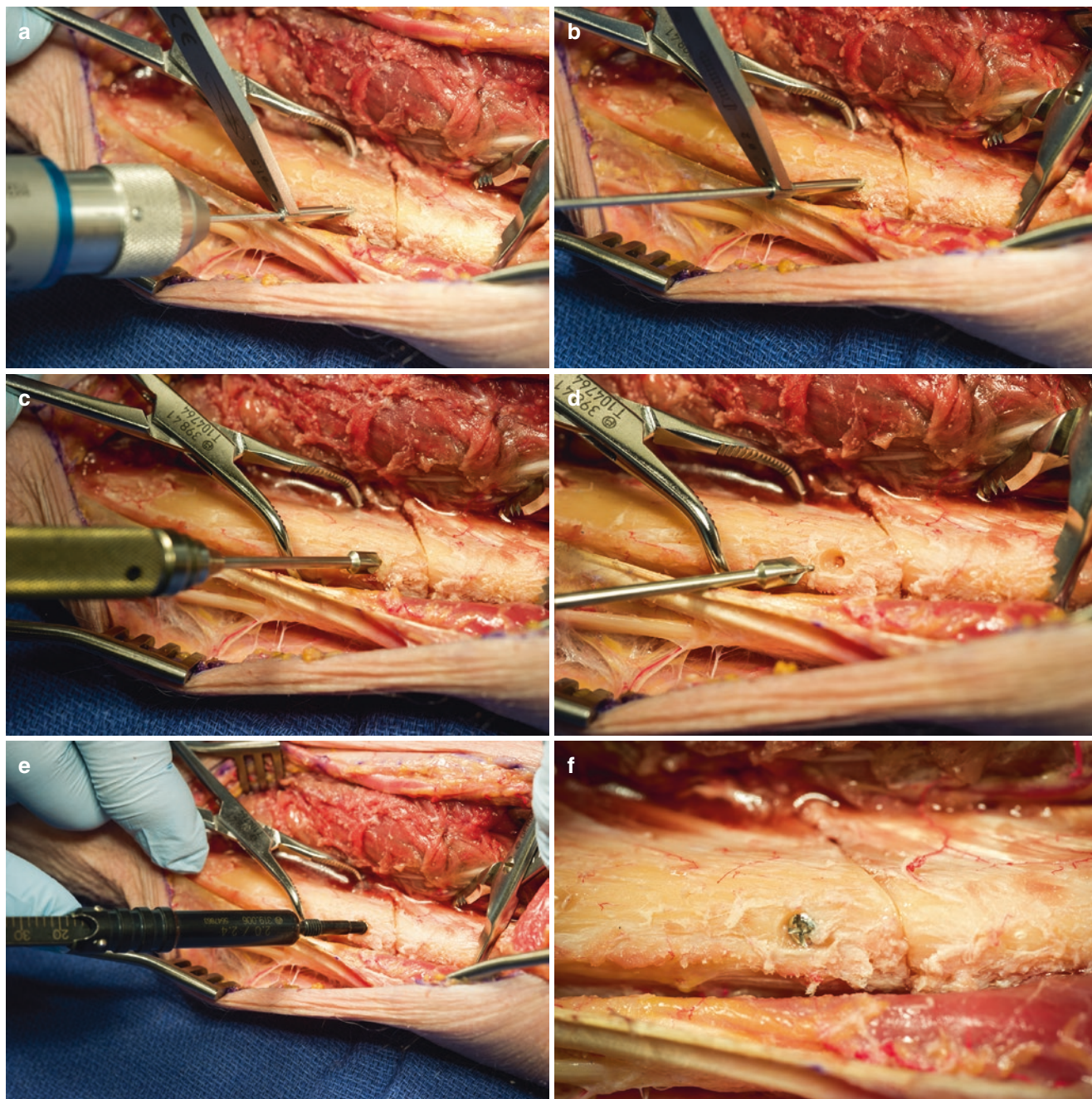
**Fig. 21.57** (a) Nutrient vessel coursing into the radius. (*Note to Junior residents:* This vessel causes the line in the radial shaft that the ER will call you about, as a radial shaft fracture.) (b) Clinical example of nutrient vessel course in the radius (*arrow*)



**Fig. 21.58** Anterior plate positioning for proximal radial shaft fractures after PT elevation



**Fig. 21.59** Oblique osteotomy; fracture created in the radial shaft



**Fig. 21.60** Utilization of lag screw for provisional fixation following reduction. (a) Drill a bicortical pilot hole from distal radius to proximal ulna with a 1.5-mm drill bit. (b) Over-drill near cortex with 2.0-mm

drill bit. (c, d) Countersink in line, colinear to pilot hole. (Make full turn, don't oscillate.) (e) Measure, generally 14–18 mm. (f) Insert and screw





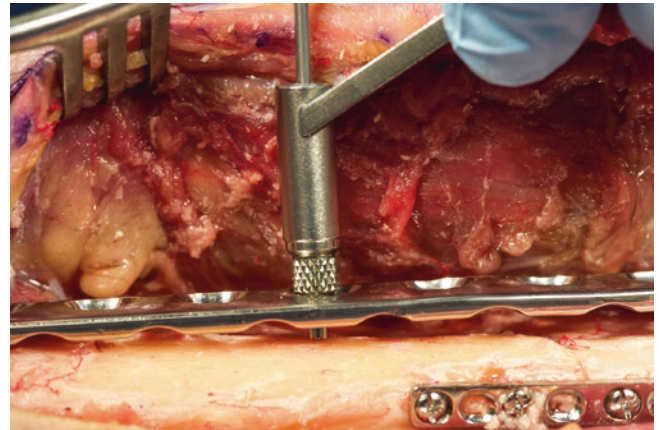
**Fig. 21.61** Provisional fixation option with mini-fragment plate, pre-drilling unicortical pilot hole with 1.5-mm drill bit



**Fig. 21.62** 8-hole 2.0-mm dynamic compression plate (DCP) contoured to radial bow and positioned to create axilla for compression

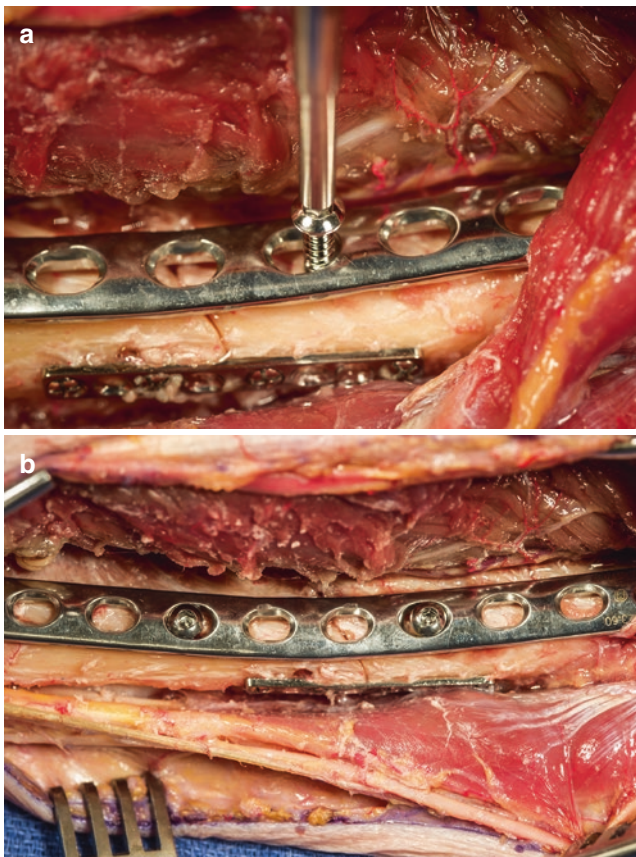


**Fig. 21.63** Compression screw inserted. Note distal eccentric hole drilling and screw insertion with one more screw placed proximally and distally

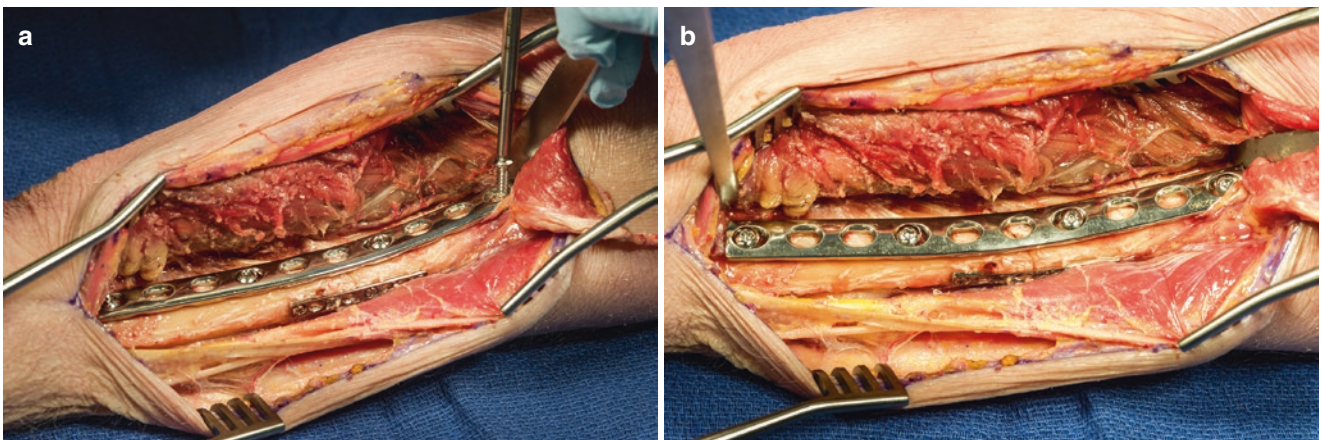


**Fig. 21.64** Plate positioned, first pilot drilling distally, and screw inserted





**Fig. 21.65** (a, b) Proximal screw inserted in compression, which can be performed with mini-fragment plate in place

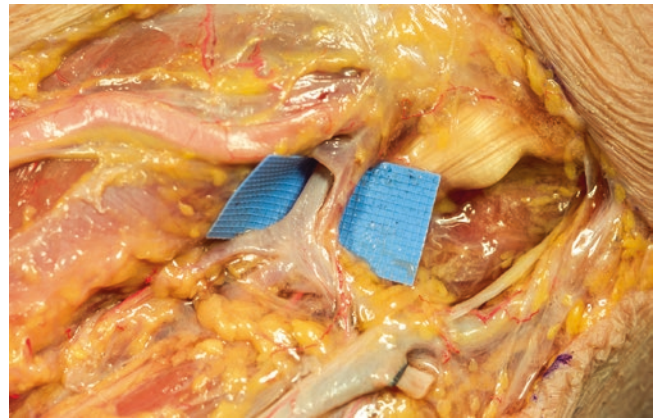


**Fig. 21.66** (a, b) Distal screw has been inserted, followed by proximal insertion. Note that the compression screws are closer to the fracture, osteotomy

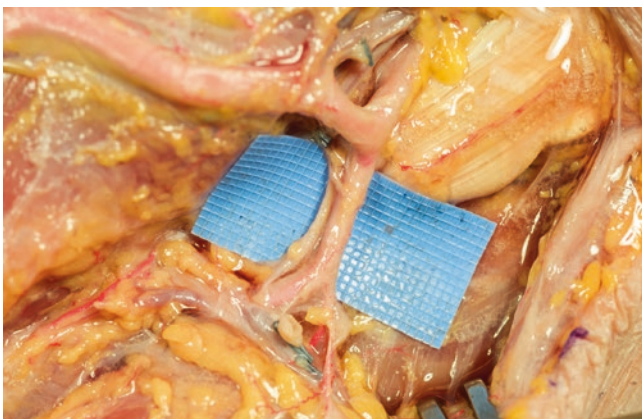




**Fig. 21.67** Proximal radial shaft approach will require incision crossing the antecubital fossa on an angle radially, with identification of the basilic and cephalic venous system interconnection



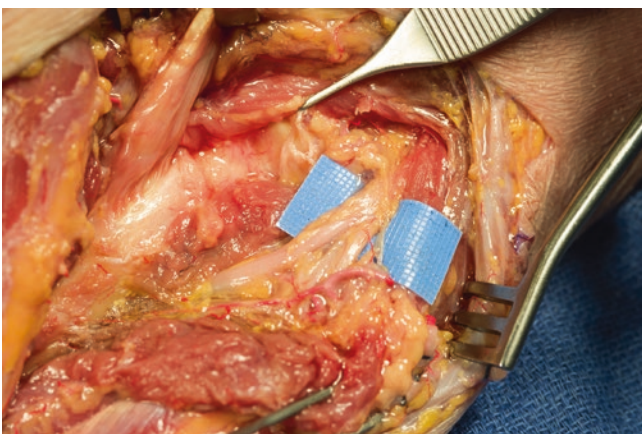
**Fig. 21.68** Venous branches divided, often with Ligaclip® application. Blue background under radial recurrent artery and vein, which give off the leash of Henry



**Fig. 21.69** Blue background behind radial recurrent artery and vein



**Fig. 21.70** Radial recurrent artery and vein divided



**Fig. 21.71** Blue background behind radial nerve with posterior interosseous nerve coursing through the dissected supinator. Pickups are holding the split distal edge of the annular ligament, allowing access to the radial neck



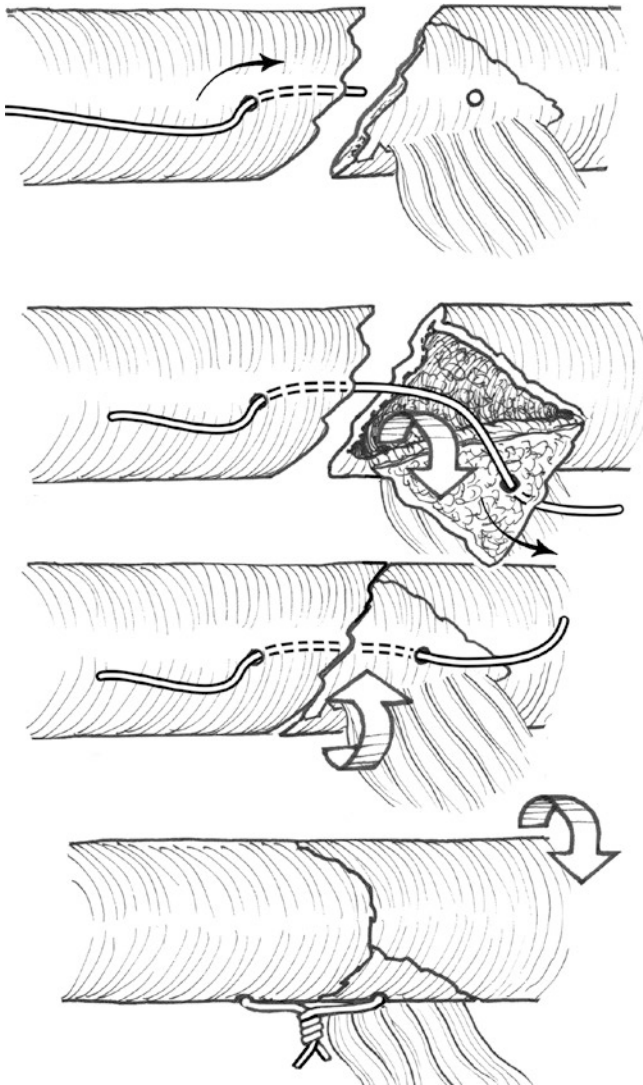
**Fig. 21.72** Course of the radial artery if taken radially and not ulnarly, making proximal shaft and neck access difficult



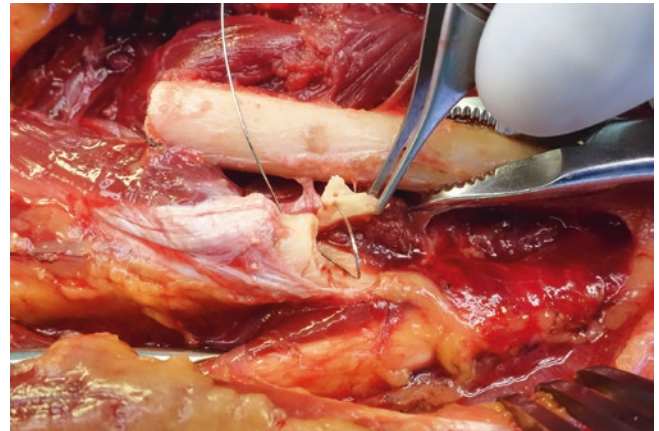
### 21.4.1 Butterfly Fragment Reduction and Alignment

Fractures associated with a butterfly fragment critical to reduction and overall alignment fixation may be addressed with a number of techniques. These include interosseous

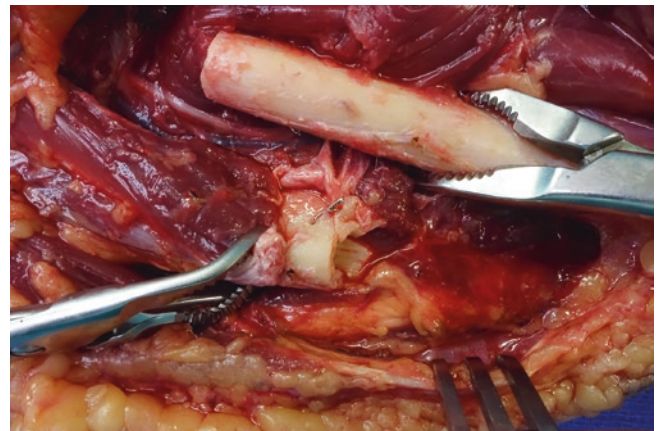
wires, which are inserted using rotation of the butterfly fragment for passage of the wire through the endosteal surface of the butterfly fragment after hole drilling. The wire is passed first through the stable, constant fragment (Figs. 21.73, 21.74, 21.75, 21.76, 21.77, 21.78, 21.79, 21.80, and 21.81).



**Fig. 21.73** Wire passage from stable fragment to rotated butterfly fragment for provisional reduction and fixation

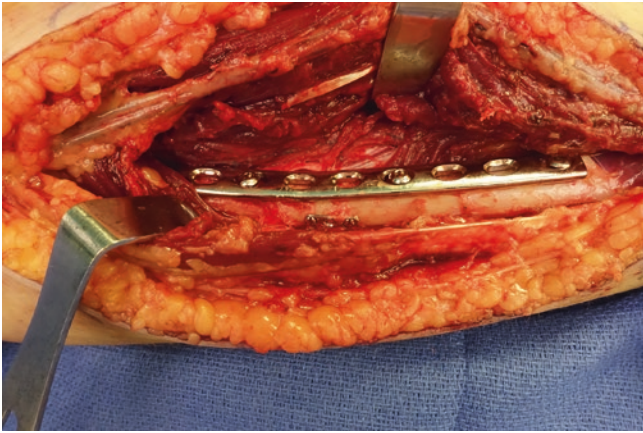


**Fig. 21.74** Interosseous wire fixation of butterfly fragment, rotating the mobile butterfly fragment feeding wire through the endosteal hole, in same case as presented in Figs. 21.30, 21.31, and 21.32



**Fig. 21.75** Wire tightened

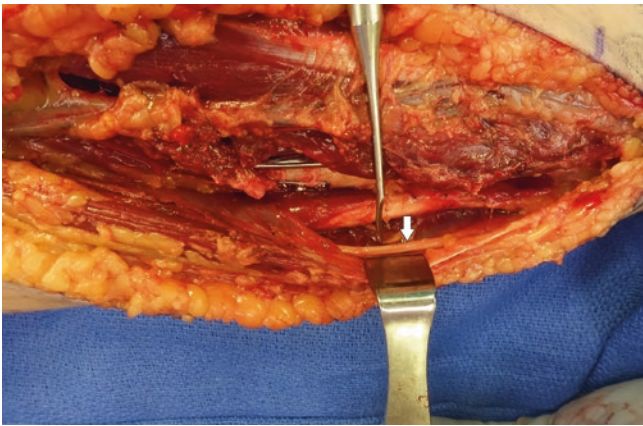




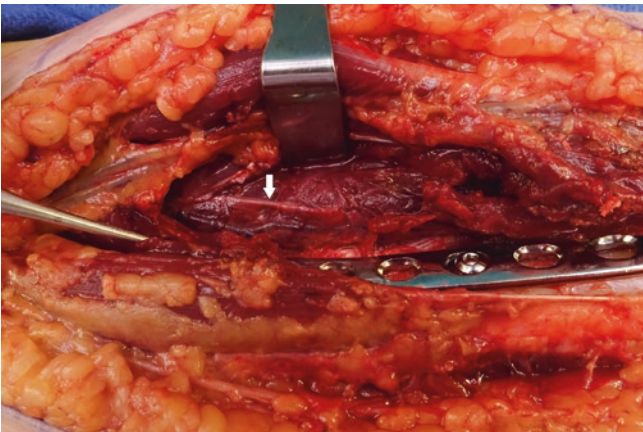
**Fig. 21.76** Final radius fixation



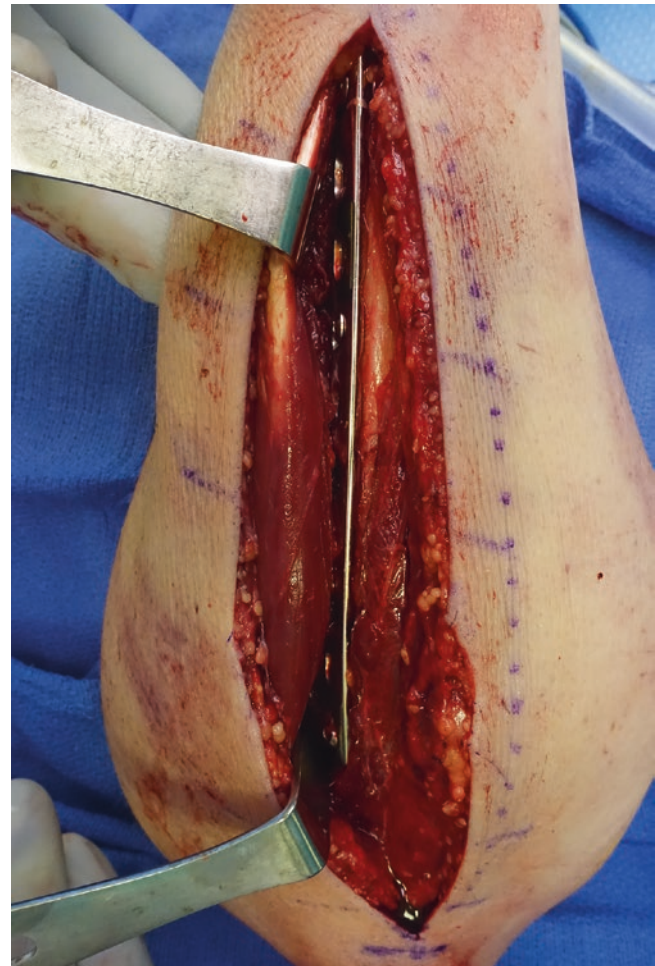
**Fig. 21.77** Lateral antebrachio-cutaneous (LABC) nerve



**Fig. 21.78** Dorsal superficial branch of the radial nerve (SBRN) (arrow)

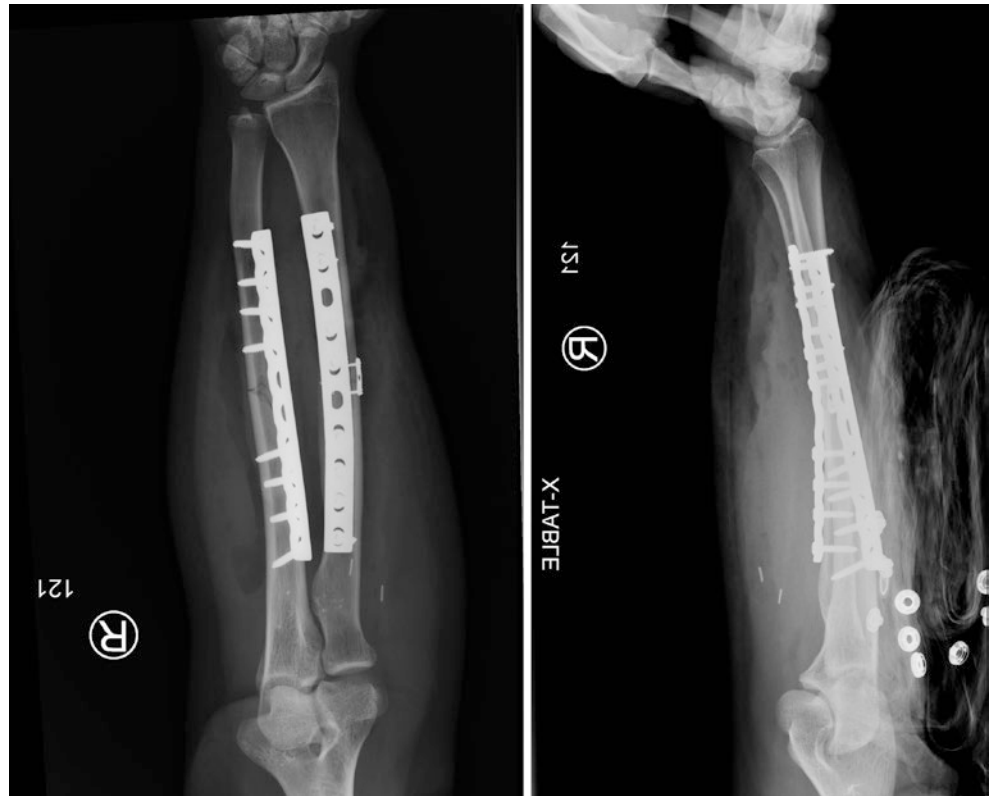


**Fig. 21.79** Anterior interosseous nerve (arrow)



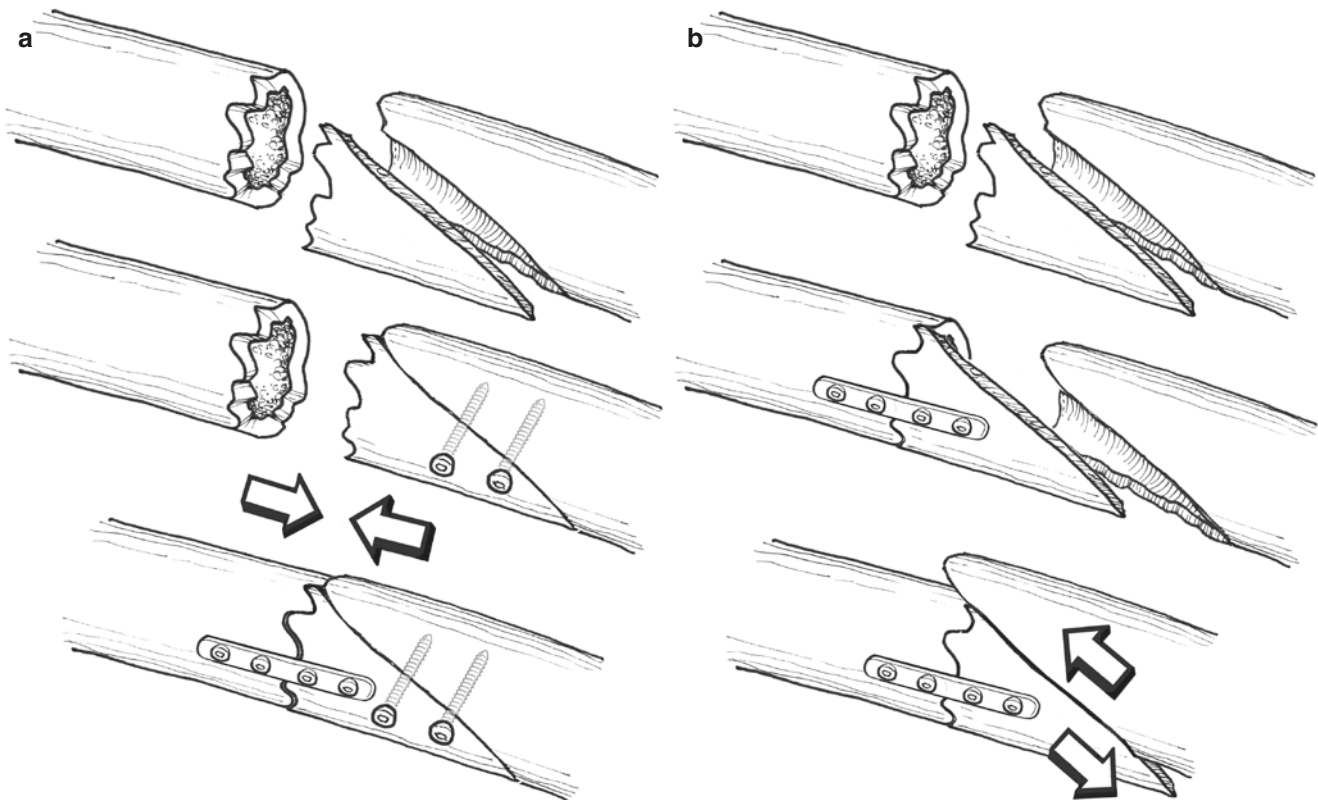
**Fig. 21.80** Completed ulna fixation

**Fig. 21.81** Radiographs following ORIF



Butterfly fragments that have an oblique and a transverse component should be addressed first with reduction and fixation of the oblique portion, followed by the transverse

component, to prevent shearing caused by ORIF done the other way around (Figs. 21.82, 21.83, 21.84, 21.85, 21.86, 21.87, 21.88, and 21.89).

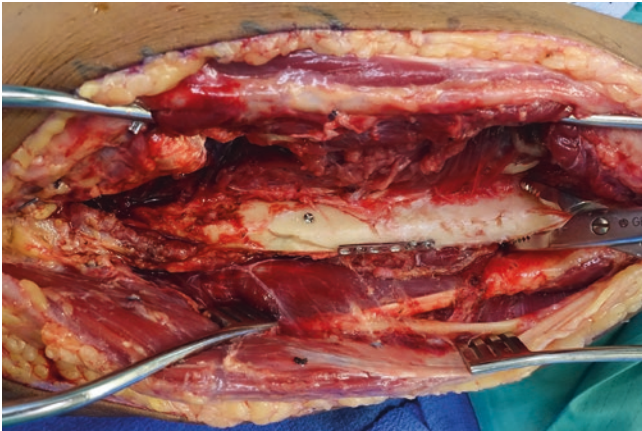


**Fig. 21.82** (a) Beginning fixation of the butterfly fragment with the oblique or shearing component first makes the next step easier. (b) Fixing the transverse component first makes holding the reduction more difficult because of the tendency to shear

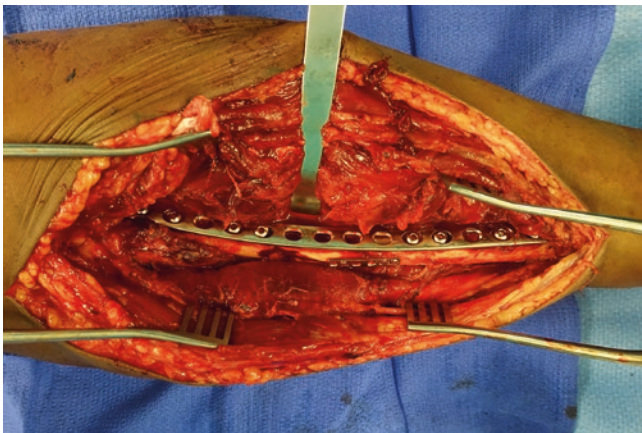


**Fig. 21.83** Injury radiographs of right radius and ulna shaft fractures with an oblique and transverse butterfly fragment of the radius





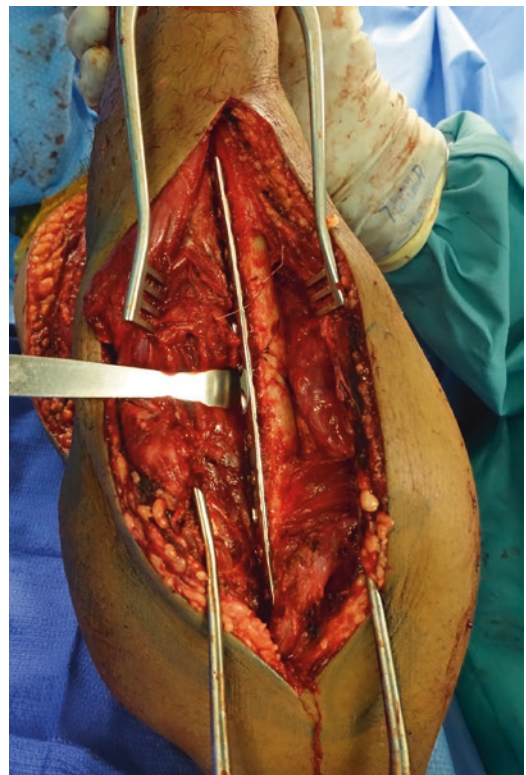
**Fig. 21.84** Provisional fixation of the radius with lag screw fixation first, followed by reduction and mini-fragment plate fixation



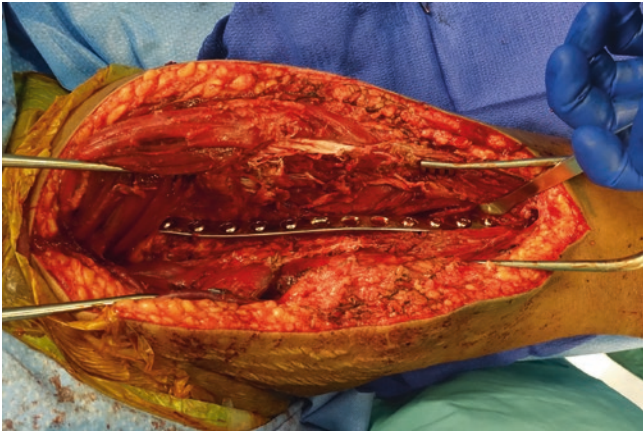
**Fig. 21.86** Definitive radius fixation



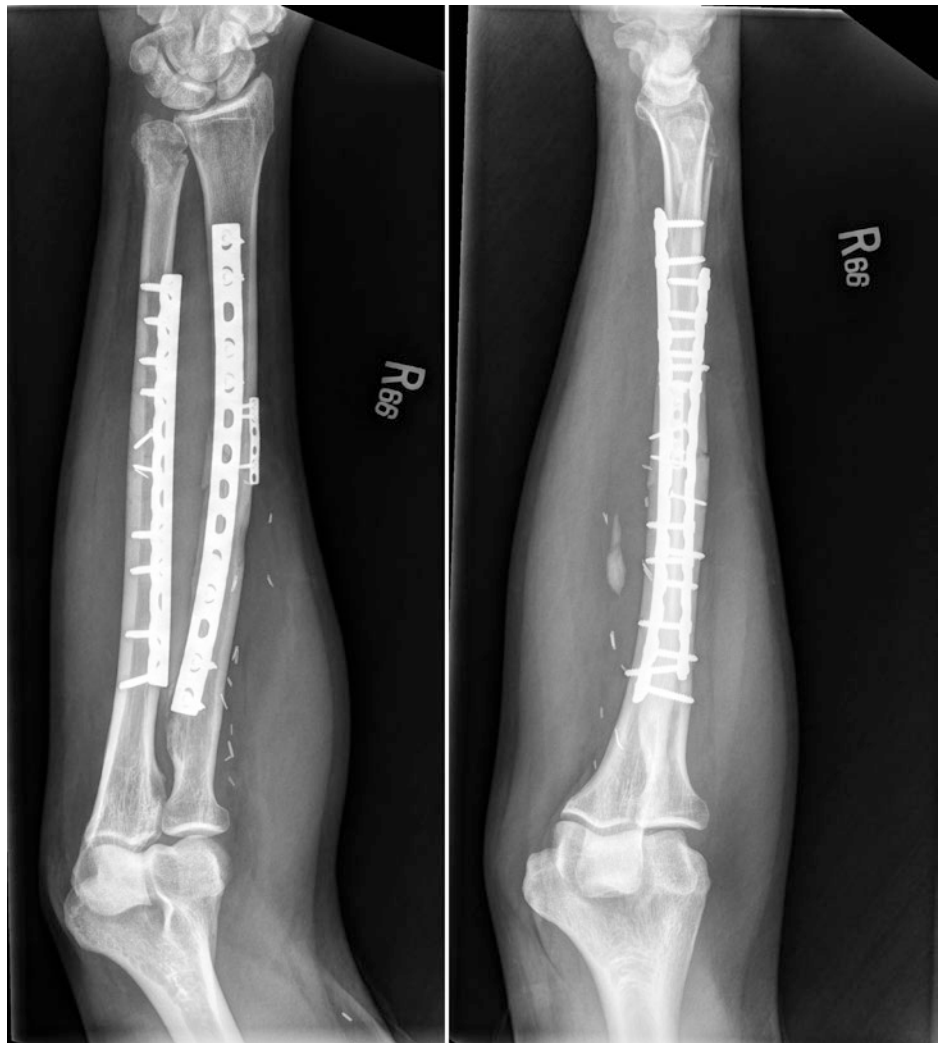
**Fig. 21.85** Provisional fixation of the ulna with mini-fragment lag screws



**Fig. 21.87** Definitive ulna fixation with closure of fracture gaps



**Fig. 21.88** Fixation of humerus; the patient had a floating elbow



**Fig. 21.89** Radiographs following ORIF; the distal ulna fracture was treated nonoperatively



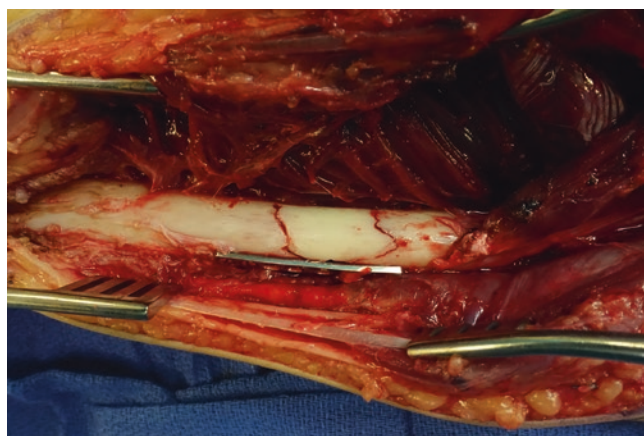
In the scenario of an open fracture with a butterfly fragment that is thought to be critical to attaining proper alignment (i.e., length, rotation, angulation), the fragment can be

inserted, stabilized, and then removed after the definitive fixation (Figs. 21.90, 21.91, 21.92, and 21.93).

**Fig. 21.90** Injury radiographs of open left radius and ulna fracture with large, detached butterfly fragment



**Fig. 21.91** Ulnar incision with dorsal laceration excluded from approach incision



**Fig. 21.92** Provisional fixation of radius with removal of devitalized butterfly fragment after alignment was attained, followed by allograft and vancomycin mixture



**Fig. 21.93** Radiographs following ORIF, with removal of large butterfly defect (*arrow*) from radius after fixation

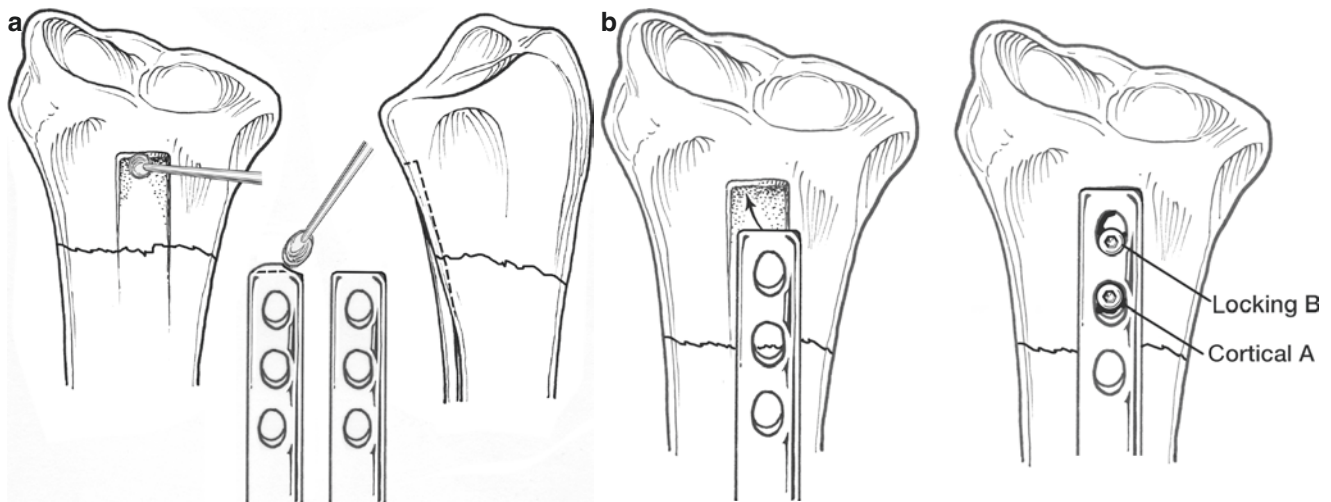


### 21.4.2 Fixation Plates

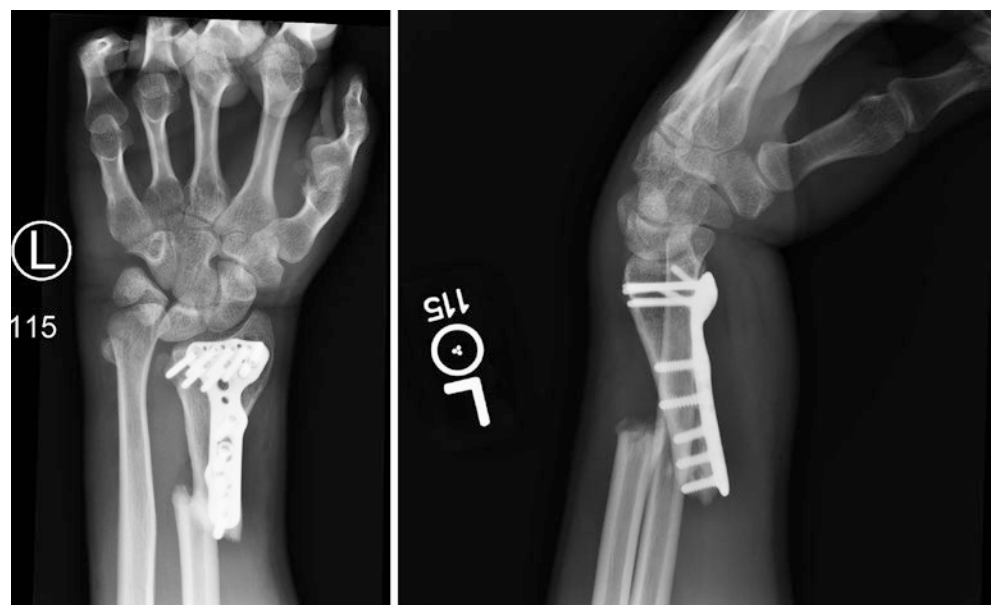
Plate fixation usually uses a compression plate, but occasionally a locking plate will be used. The preferred plate size is 3.5 mm. The initial work done on fixation of a forearm fracture used a 4.5-mm plate, and early recommendations were for five cortices on either side of the fracture. But once the 3.5-mm plates came along, the recommendation was seven cortices. Studies both clinical and biomechanical have demonstrated the utility of a four-screw construct, with two on each side of the fracture. The importance of the working length of the plate was emphasized, using fewer screws with the longer plate. The ability of this construct to withstand weight-bearing in a multi-trauma patient is unclear [7, 9, 19].

I generally use a 3.5-mm non-locking construct, except for the most distal fractures. In those cases, I use a locking screw at the very end of the metaphyseal bone, but I am very

reluctant to use locking screws in the shaft. I prefer four screws over five holes on each side of the fracture to increase the working length, as one of the efforts is to allow weight-bearing and use of the arm in an unrestricted fashion, particularly in a multi-trauma patient. The “extra screw” on either side is also occasionally referred to as the “resident” screw. (Figure it out.) I also try to curve the plate to the bow of the radius, and I implement other principles such as acute plate pre-stressing and stable rigid internal fixation. In certain situations, the fracture of the radius may be distal, precluding “routine” plating, yet it is too proximal to justify an extended distal radius plate. A technique is to recess or notch the distal radius with a burr and contour a locking plate into the metaphysis. This affords resistance to shortening and rocking, and it avoids a prominent plate against the flexor tendons distally (Figs. 21.94, 21.95, 21.96, 21.97, 21.98, 21.99, 21.100, 21.101, 21.102, and 21.103).

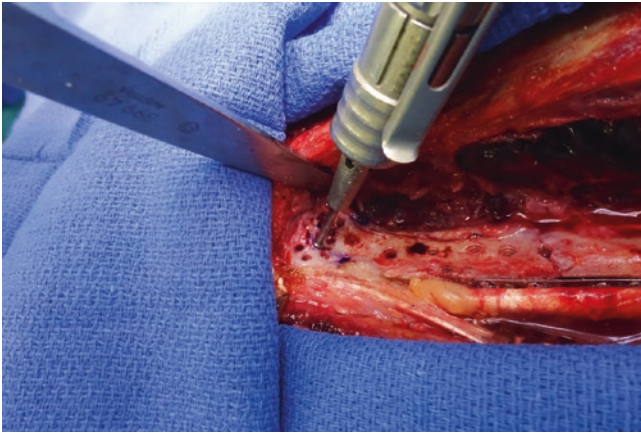


**Fig. 21.94** (a) Recessing the distal radius to accept a contoured plate. (b) Sequence of screw insertion to seat the plate in the recessed radius

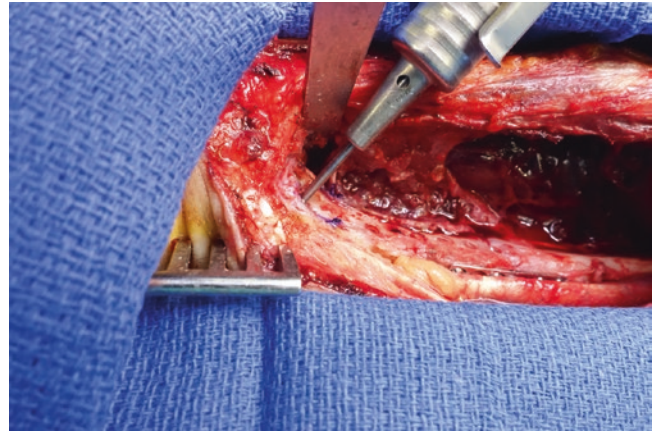


**Fig. 21.95** Injury radiographs with fracture through proximal screw in previous plate

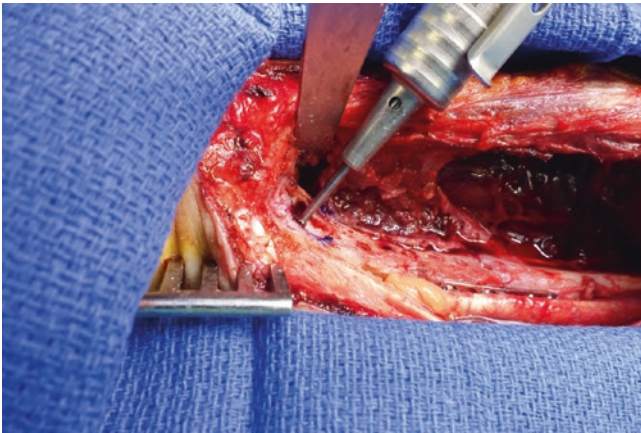




**Fig. 21.96** Preparation of metaphysis for recessed plate



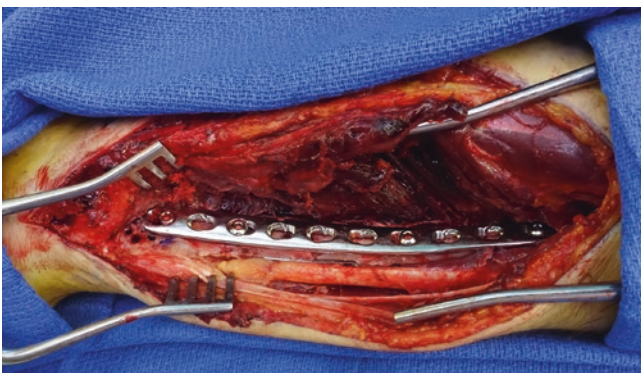
**Fig. 21.97** Recessing with burr



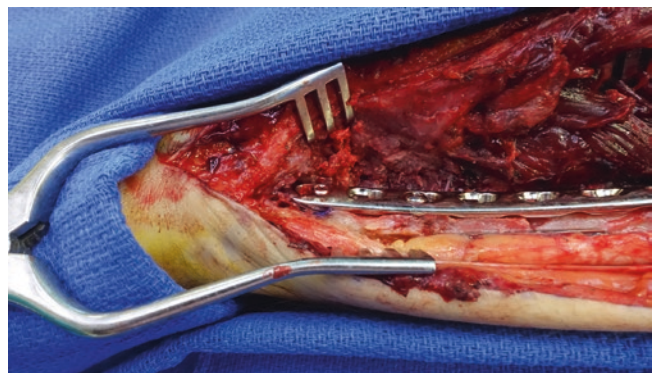
**Fig. 21.98** Undercutting with side of burr



**Fig. 21.99** Plate cut to rest against trough edge distally

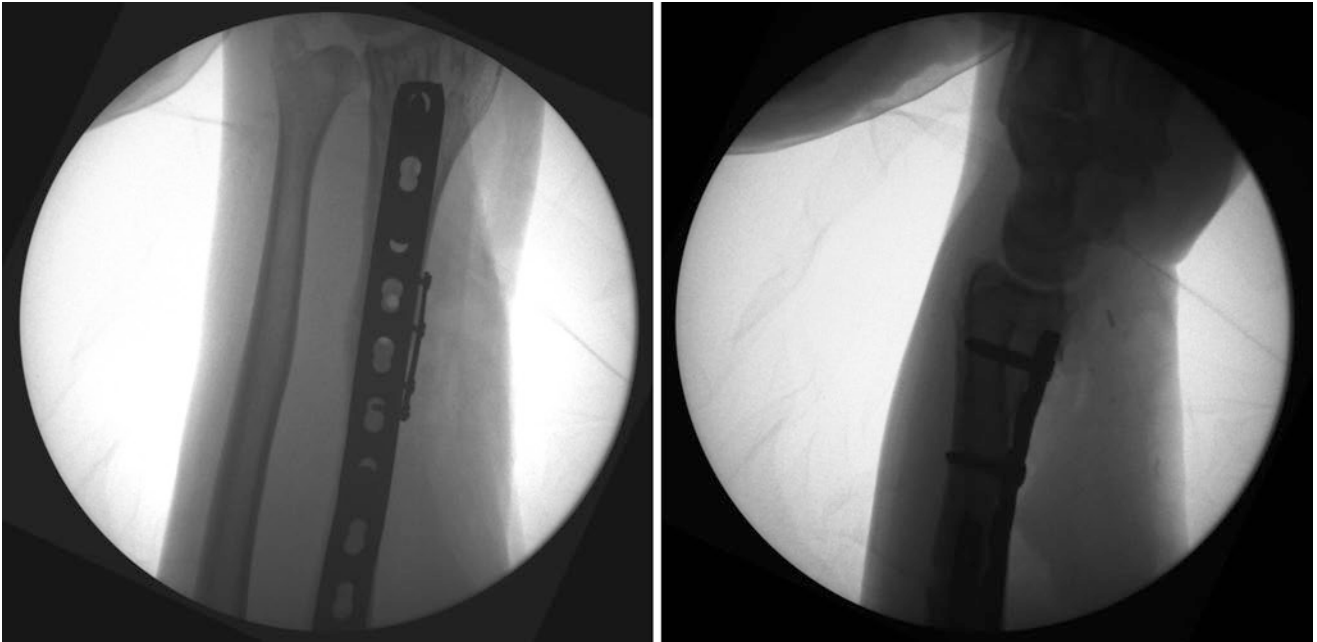


**Fig. 21.100** Plate seated in trough



**Fig. 21.101** Flush surface distally





**Fig. 21.102** Intraoperative radiographs showing recessed distal aspect of plate



**Fig. 21.103** Final radiographs following lateral ORIF

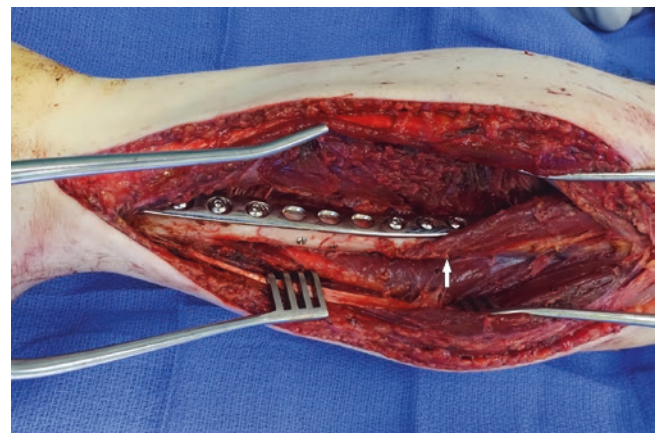
In a trauma setting, I frequently put in two screws on both sides of the fractures, with the most important screws being closest to the fracture and farthest away; I then address the ulna. I return to complete the screw insertion in the radius after the ulna fixation is completed, if the patient is stable. The ulna is reduced in a fashion similar to the

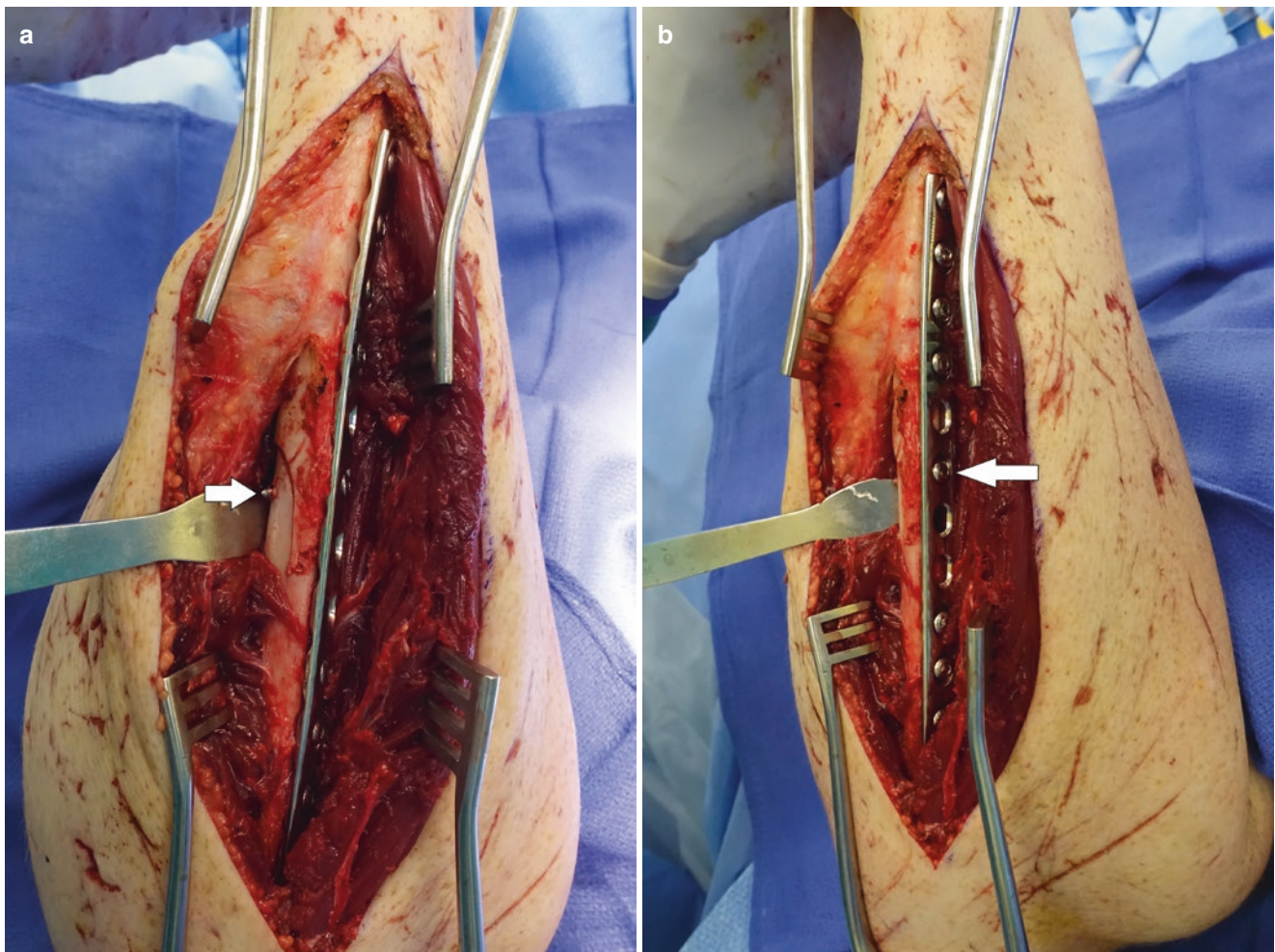
reduction of the radius, using either mini-fragment fixation, lag screw fixation outside of or through the plate, or provisional Kirschner wire (K-wire) fixation, followed by a dorsal plate for the ulna on the flat surface of the ulna, particularly distally (Figs. 21.104, 21.105, 21.106, 21.107, and 21.108).

**Fig. 21.104** Injury radiographs of open left radius and ulna shaft fractures. Note thumb amputation at interphalangeal joint (arrow)



**Fig. 21.105** Fixation following provisional fixation followed by definitive fixation of the radius with pronator teres remaining inserted (arrow)





**Fig. 21.106** (a, b) Ulna fixation with use of shaft screw to capture butterfly fragment and lag into proximal ulna fragment (*arrow*)



**Fig. 21.107** Shaft screw that is not self-tapping, with no threads and outer diameter equal to glide hole



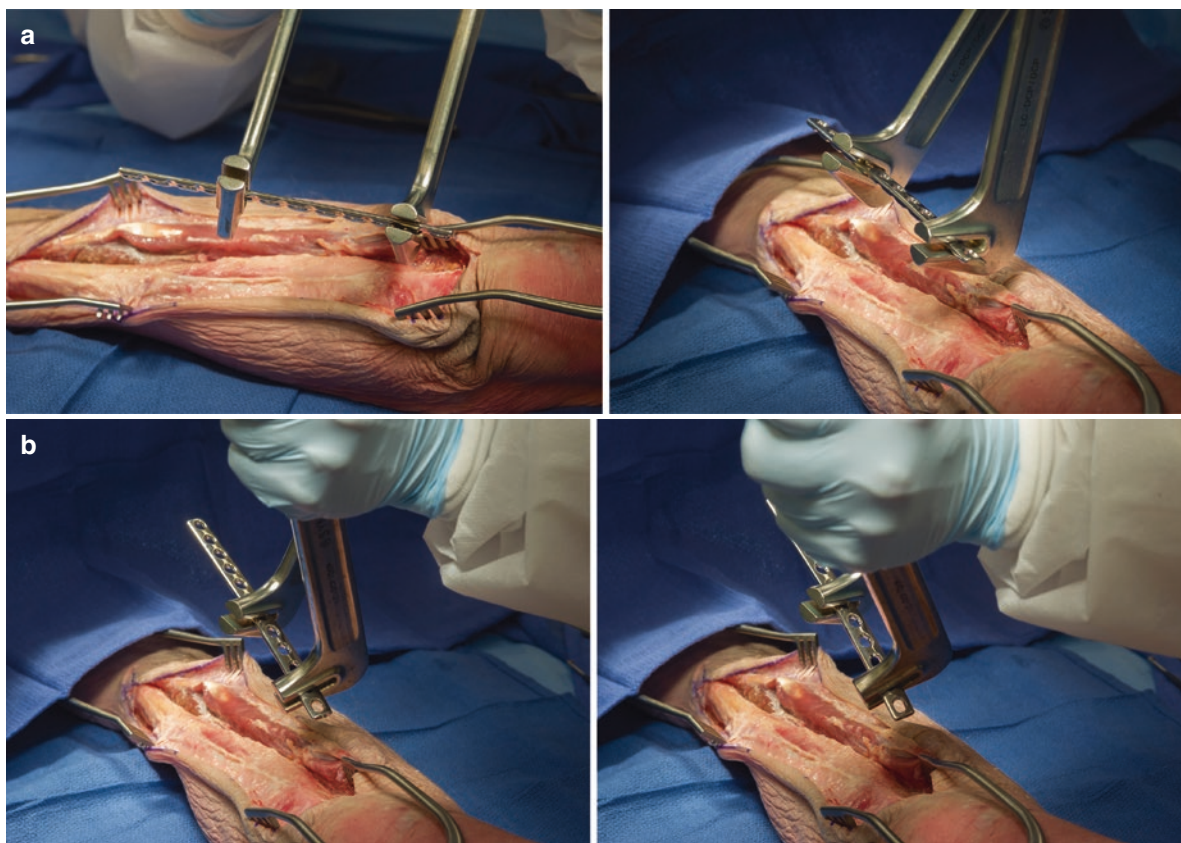
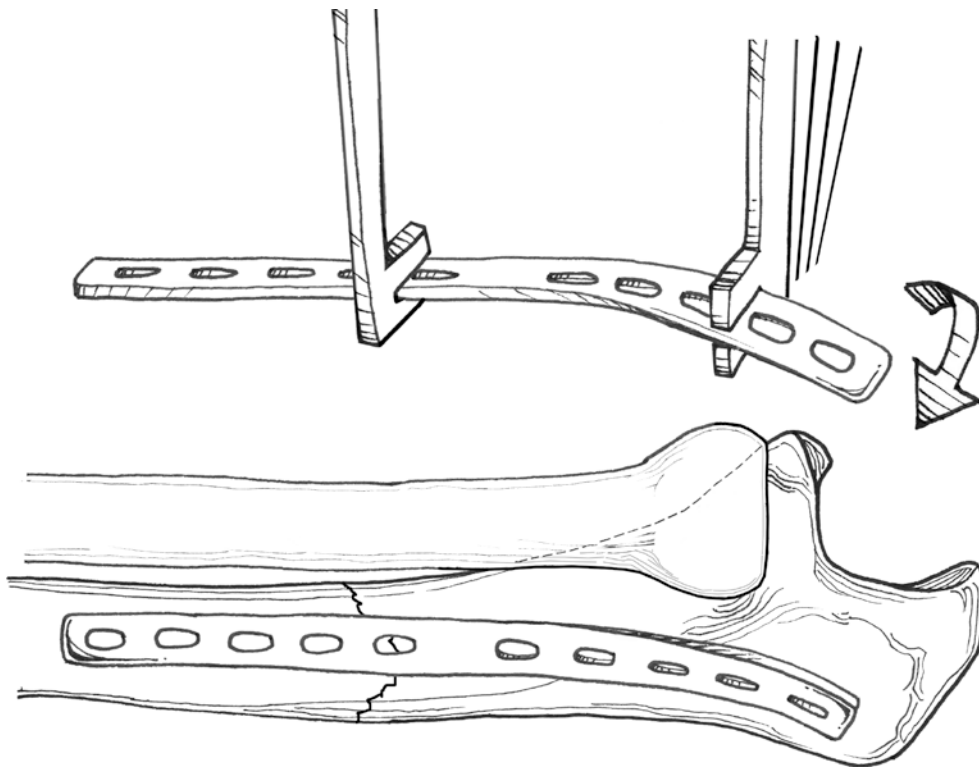
**Fig. 21.108** Radiographs following ORIF including lag screw fixation through ulna plate for reduction of butterfly fragment (*arrow*)



The proximal fixation of the ulna requires a bend and torqueing of the plate to account for the 11–17° bend of the ulna proximally. This can be done with bending irons in one

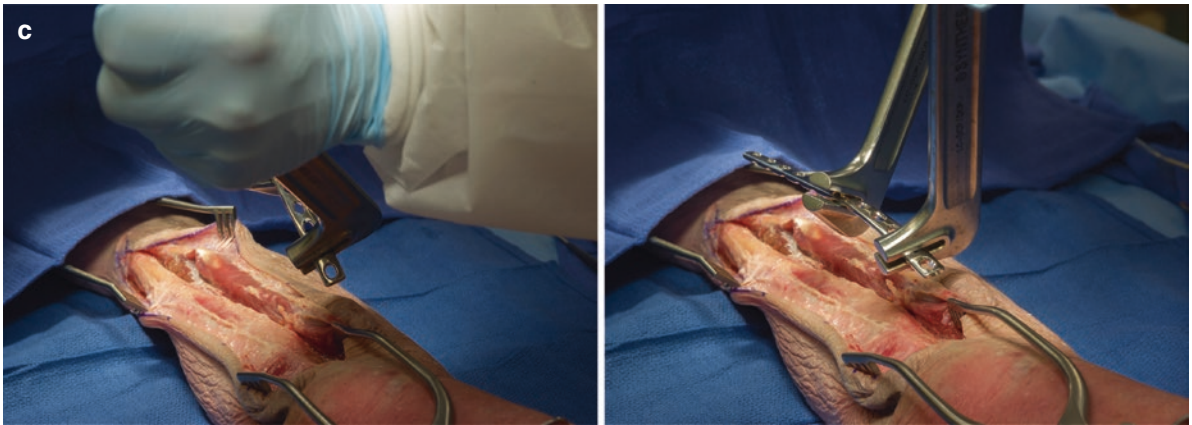
motion: bending and turning or torqueing (Figs. 21.109, 21.110, 21.111, 21.112, 21.113, 21.114, 21.115, 21.116, 21.117, 21.118, and 21.119).

**Fig. 21.109** Technique of bending and twisting plate with bending irons



**Fig. 21.110** (a–c) Plate bend for proximal ulna shaft fractures requires a bend and twist to account for proximal ulna bow

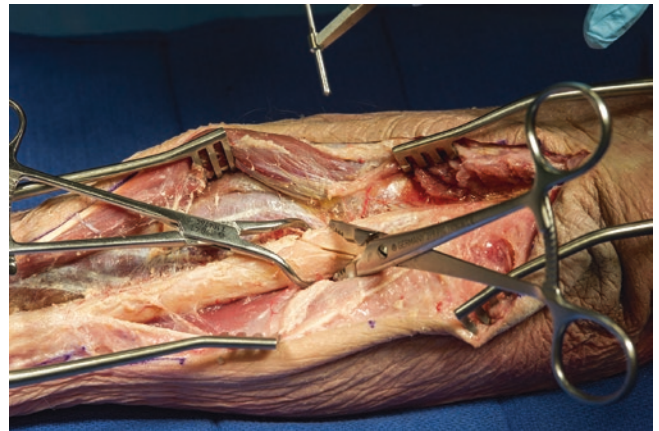




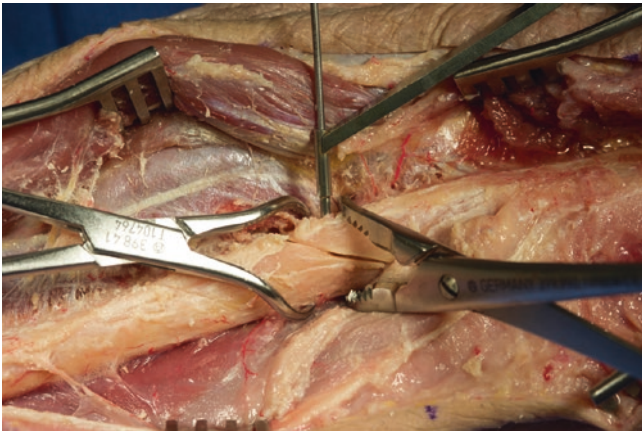
**Fig. 21.110** (continued)



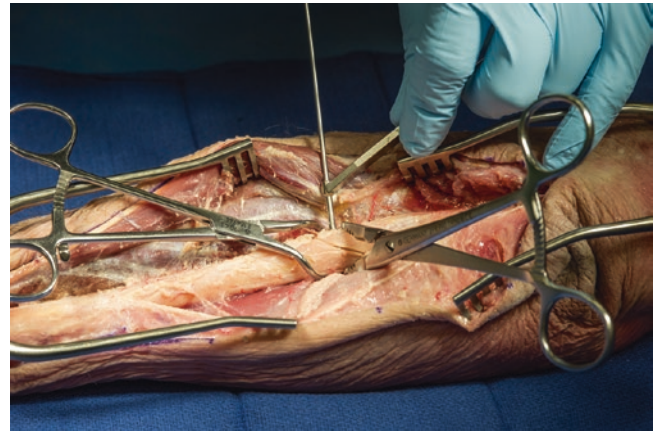
**Fig. 21.111** Plate positioned on ulna



**Fig. 21.112** Oblique osteotomy fracture with reduction clamps in preparation for lag screw

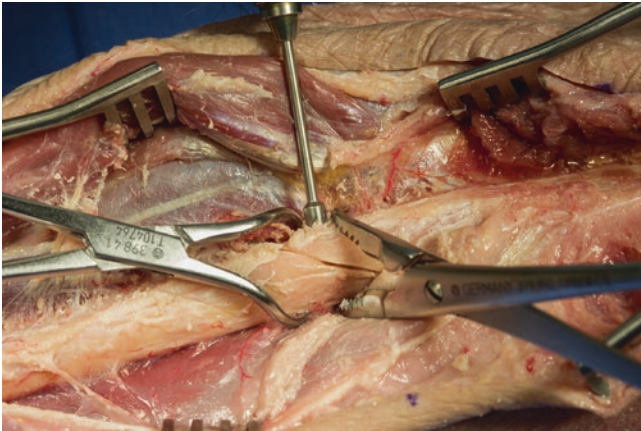


**Fig. 21.113** Bicortical pilot hole drilled with 1.5-mm drill bit



**Fig. 21.114** Near cortex over-drilled with 2.0-mm drill bit

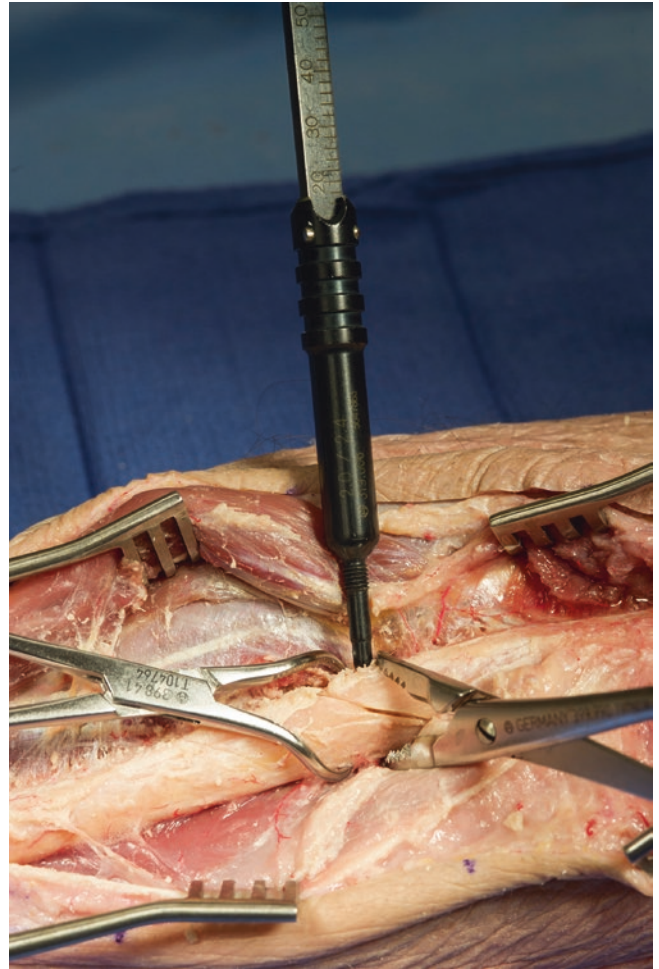




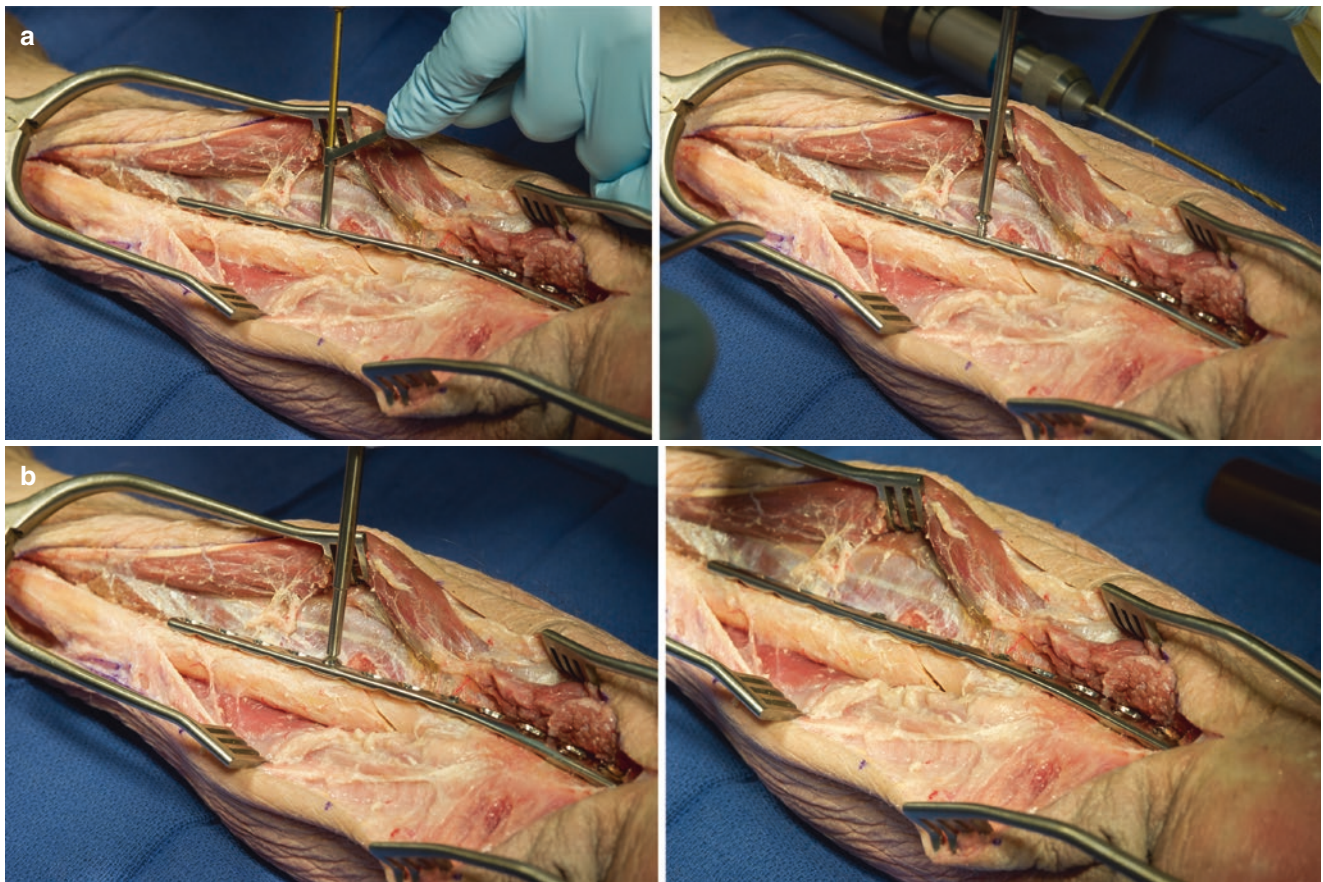
**Fig. 21.115** Countersinking



**Fig. 21.117** The plate is positioned and the initial screw is inserted proximally to help control plate alignment, but the screw is not completely seated. The distal screw will create the axilla when inserted and seated



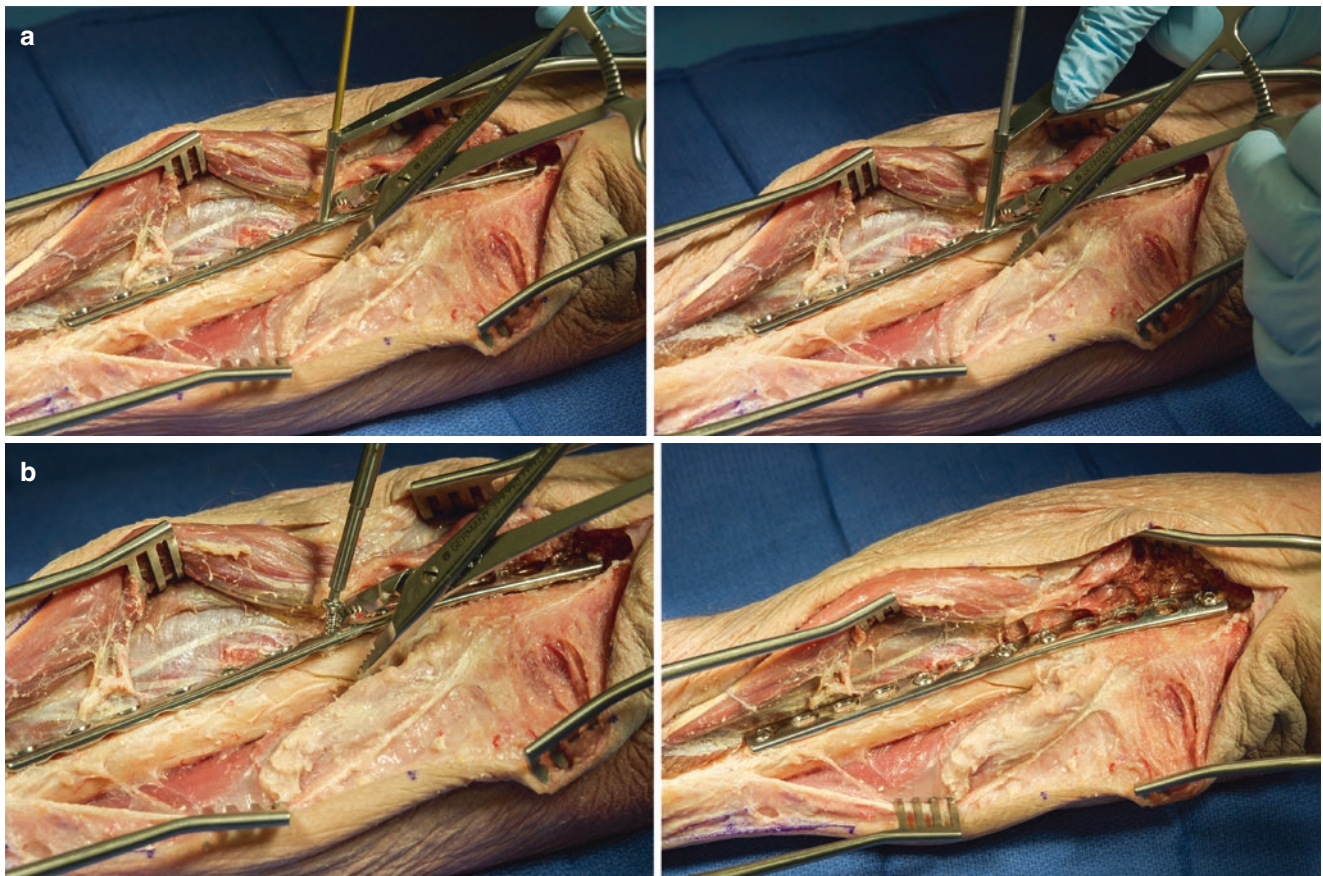
**Fig. 21.116** Depth gauge for screw length, followed by screw insertion



**Fig. 21.118** (a) (1) Distal screw drilled in compression but not completely seated until proximal screws are checked to ensure that they will create the compression when tightened after the distal screw is completely seated. Note proximity to fracture of inboard screws. You can

still compress even with the mini-fragment screw in place if you use a provisional lag screw. (2) Screw insertion. Note the distal position in the plate. (b) (1) Screw seated. (2) Proximal screw seated and tightened to provide compression into axilla





**Fig. 21.119** (a) (1) Lag screw insertion through plate if preliminary lag screw was not utilized, beginning with 2.5-mm drill bit, then 3.5-mm drill bit, then screw insertion. A shaft screw can be used if available, but would require tapping first. (2) Near cortex over-drilled with

3.5-mm drill bit for glide hole. (b) (1) 3.5-mm cortical lag screw insertion. (2) Final fixation. In a clinical situation, two more screws would be inserted proximally and distally



Although the preferred plate size is 3.5 mm, with four screws proximally and distally, I have no problem with utilizing a 2.7-mm plate in a smaller patient. In such cases, I use three screws distally, and in very distal fractures, a single cortical screw distally and a locking screw or two cortical screws. Depending on the length of the fracture complex, a

locking T-plate, a third tubular plate, or a combination of devices can be used proximally or distally (Figs. 21.120, 21.121, 21.122, 21.123, 21.124, 21.125, 21.126, 21.127, 21.128, 21.129, 21.130, and 21.131). I generally call for intraoperative flat plates, not C-arm radiographs, when I put in the next-to-last screw.

**Fig. 21.120** Injury radiographs of segmental right radius and ulna shaft fracture



**Fig. 21.121** Radiographs following ORIF with two screws in distal ulna fragment. Note “bouquet” fixation of a small metacarpal



**Fig. 21.122** Injury radiographs of right radius and distal ulna fractures. The patient also sustained left radius and ulna fractures

**Fig. 21.123** Radiographs demonstrating union following ORIF including utilization of a mini-locking plate on the ulna



**Fig. 21.124** Injury radiographs of open left radius and ulna shaft fractures



**Fig. 21.125** Radiographs following ORIF with two 2.7-mm mini-fragment plates consequent to soft tissue constraints limiting incisions



**Fig. 21.126** Radiographs of open right radius and distal ulna shaft fractures



**Fig. 21.127** Radiographs of open left radius and ulna shaft fractures



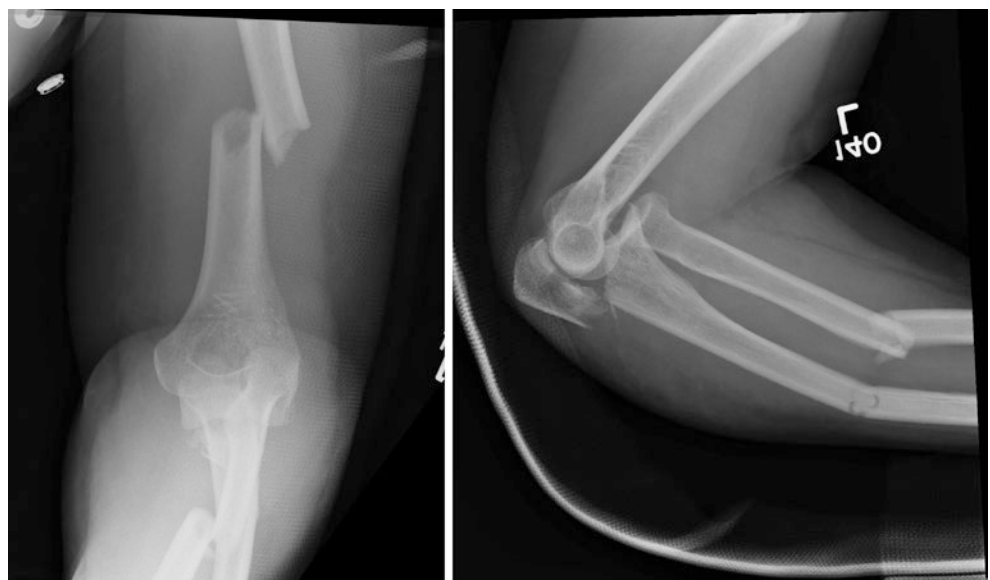
**Fig. 21.128** Radiographs following ORIF of the right radius and ulna utilizing a 2.7-mm blade plate in the ulna (Cast was used because of soft tissue/tendon lacerations.)



**Fig. 21.129** Radiographs following ORIF of the left radius and ulna, including a wrist fusion plate on the radius

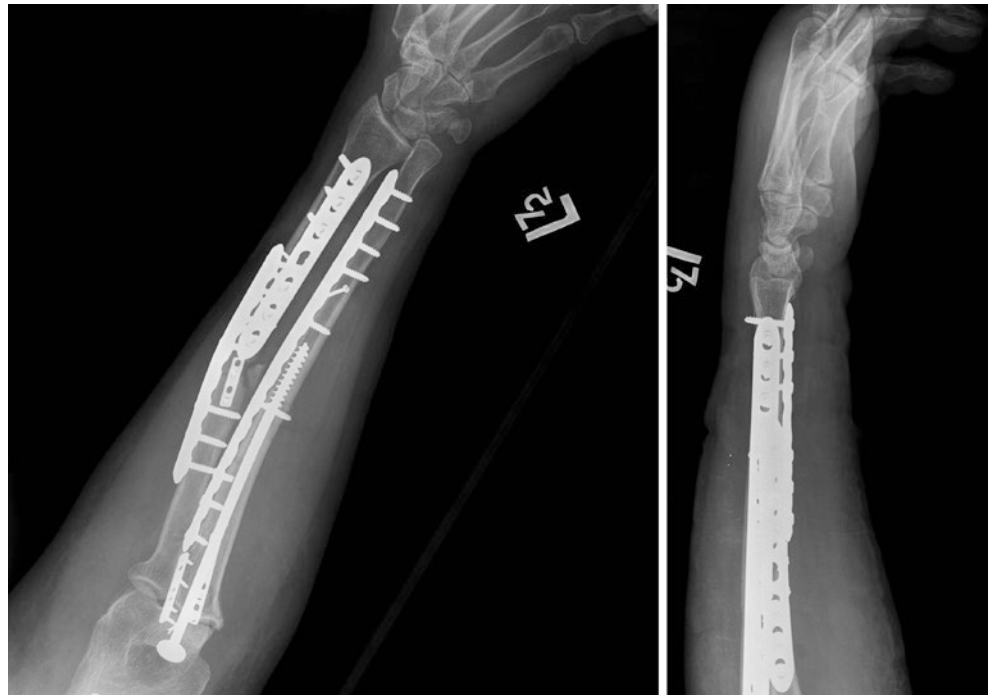


**Fig. 21.130** Injury radiographs demonstrating floating elbow with transolecranon fracture dislocation





**Fig. 21.131** Radiographs following ORIF with multiple fixation techniques including the combination of a 6.5-mm intramedullary screw and plate



## 21.5 Closure

Once the fixation is completed, the closure begins. I do not close any fascia, and I do not reattach the pronator teres. I close only the skin over drains that exit distally, beginning with the ulnar incision, followed by the radial incision. A sugar-tong splint is then applied. Depending on the patient's situation and if adequate fixation is attained, the splint is removed in 1 or 2 days, the drains are removed, and the patient is allowed to use the arm in an unrestricted fashion, including weight-bearing. In the multi-trauma situation, splints might be avoided so that the arm may be used for monitoring and access.

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## 22.1 Characteristics of Floating Elbow

Ipsilateral fractures of the humerus, radius, and ulna shaft result in a skeletally detached or floating elbow. This uncommon combination of fractures limits any one center's experience, and associated fractures, intra-articular involvement, and the inclusion of other injuries such as

Monteggia fractures confound the conclusions in various reports [1–4]. Nevertheless, several studies have looked at patient outcomes after some form of stabilization and have summarized their conclusions, as listed in Table 22.1. Nonoperative fracture treatment, such as fracture bracing, is included.

**Table 22.1** Reports of floating elbow outcomes

Authors	Year	Elbows, <i>n</i>	Summary
Yokoyama <i>et al.</i> [1]	1998	15	Functional outcomes had no correlation to Injury Severity Score (ISS), open injury, neurovascular injury, or timing of surgery.
Solomon <i>et al.</i> [2]	2003	18	Associated nerve injuries were associated with low functional outcome. Open fractures, severity of fracture, vascular injury, and concomitant intra-articular injury had no impact on outcome.
Ditsios <i>et al.</i> [3]	2013	19	Nerve injury and intra-articular involvement predisposed to worse outcome.
Jockel <i>et al.</i> [4]	2013	19	Nerve injury was associated with lower outcome score. Greater duration of follow-up improved subjective outcome.



A floating elbow reflects a high-energy injury, frequently with associated injuries. Nerve injury is associated with lower functional outcome, yet recovery may be noted over time, with the supposition that an intact nerve that was neither visualized nor functioning during surgery subsequently recovered. Another possibility is that a repaired nerve—specifically the radial nerve—recovered, with improved function.

## 22.2 Approach and Sequence of Open Reduction and Internal Fixation

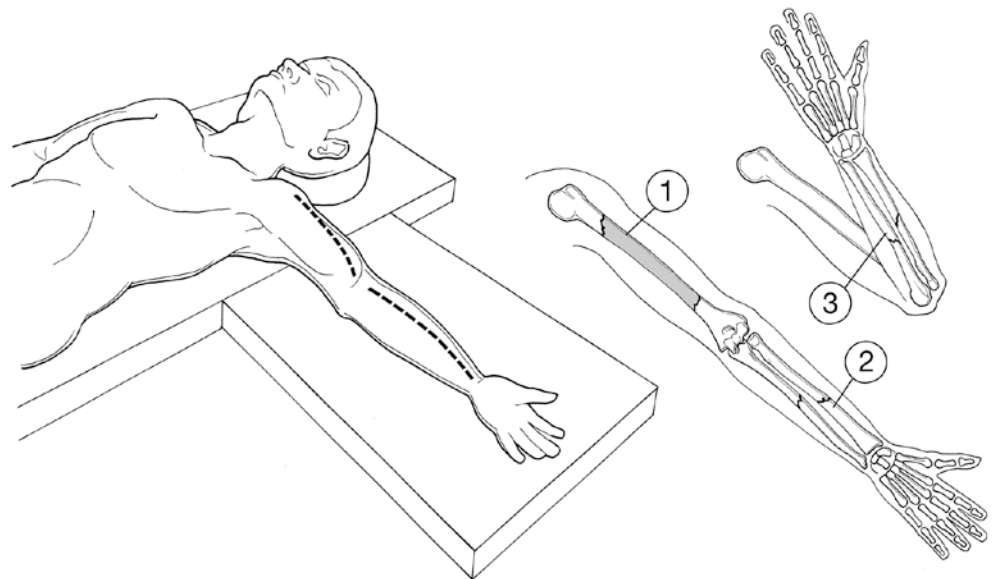
The surgical approach to the true floating elbow, which includes the combination of fractures to the shaft of the humerus, shaft of the radius, and shaft of the ulna, is driven to a significant extent by the level of the humeral fracture. The positioning selected for the patient defaults to the patient's medical condition. Certain conditions, such as cardiac, pulmonary, abdominal, and spinal considerations may

preclude lateral positioning and dictate supine positioning. The prepping and draping sequences will not be reviewed here, but are either lateral with a sterile tourniquet (*see* Chap. 10) or supine with a sterile tourniquet (*see* Chap. 15). The following diagrammatic representations provide options for the fixation sequence and are not meant to be exclusive or rigid guidelines.

### 22.2.1 Fracture of the Humerus at the Proximal Level

The more proximal fractures of the humerus will be addressed via an anterolateral approach with lateral plating. The radius and ulna will undergo open reduction and internal fixation (ORIF) in the “standard” fashion. The patient is supine (Fig. 22.1). The humerus is reached by anterolateral exposure, with ORIF and provisional closure or closure. A sterile tourniquet is applied.

**Fig. 22.1** Supine position



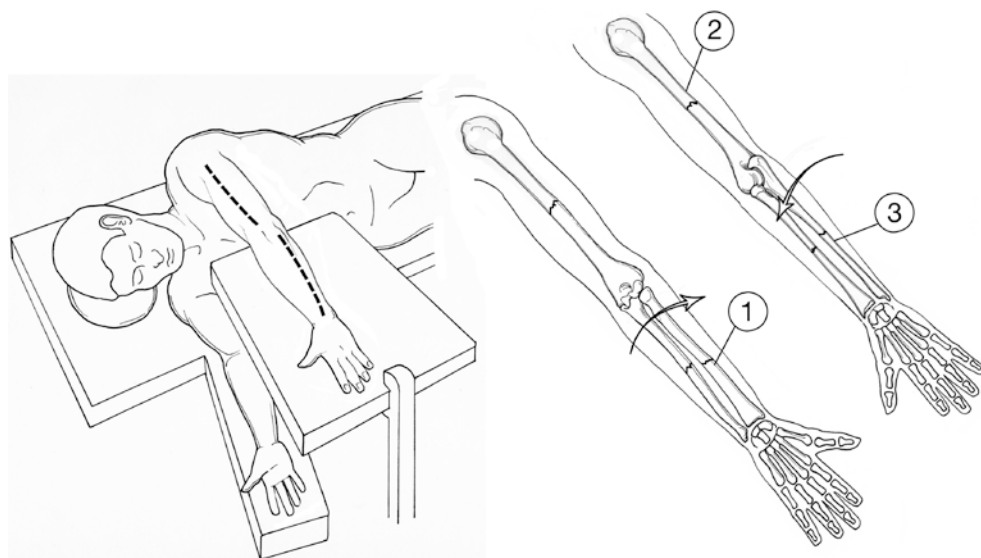
The radius and ulna are approached by anterior exposure of the radius. The elbow is flexed, and the ulna is exposed. The radius is fixed first, then the ulna is fixed, the ulna is closed, and the radius is closed.

### 22.2.2 Fracture of the Humerus at the Distal Level

If the fracture to the humerus is more distal and the posterior approach is selected, the patient is positioned lateral

(Fig. 22.2). The humerus and ulna are approached but not fixed. If the radius fracture is distal enough, the arm can be rotated through the humeral fracture: the radius is fixed, and, if swelling permits, closure is followed by fixation of the humerus and ulna.

Expose the humerus posterior, and the ulna at the dorsal subcutaneous border. Rotate through the humeral fracture for an anterior approach to the radius, perform ORIF of the radius, followed by the humerus, and finally the ulna.

**Fig. 22.2** Lateral position

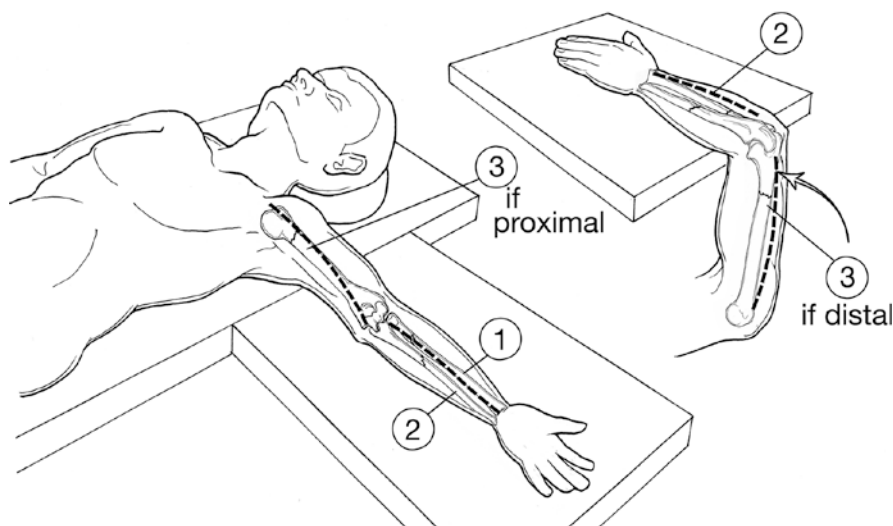
### 22.2.3 Fracture of the Humerus at Mid to Distal Level with Proximal Radial Fracture

If the fracture to the humerus is mid to distal but the patient's medical conditions preclude lateral turning, or if the fracture to the radius is proximal and requires a more unobstructed anterior approach, then the patient is maintained in a supine position. In this scenario, perform ORIF of the radius first, flex the elbow, and then fix the ulna; follow with fixation of the humerus across the chest on the padded Mayo stand. Alternatively, fix the radius, then fix the ulna and humerus with the patient's arm on the Mayo. Another option is to place the arm across the patient's chest on the padded Mayo and perform ORIF of the humerus and ulna, then the radius.

The operating room staff should be warned that humeral fixation performed posteriorly on a Mayo is tough, as the distal fragments tend to shift anteriorly and the proximal fragment rotates—so get ready for some fuming and cussing!

### 22.2.4 Fracture of the Radius at Any Level

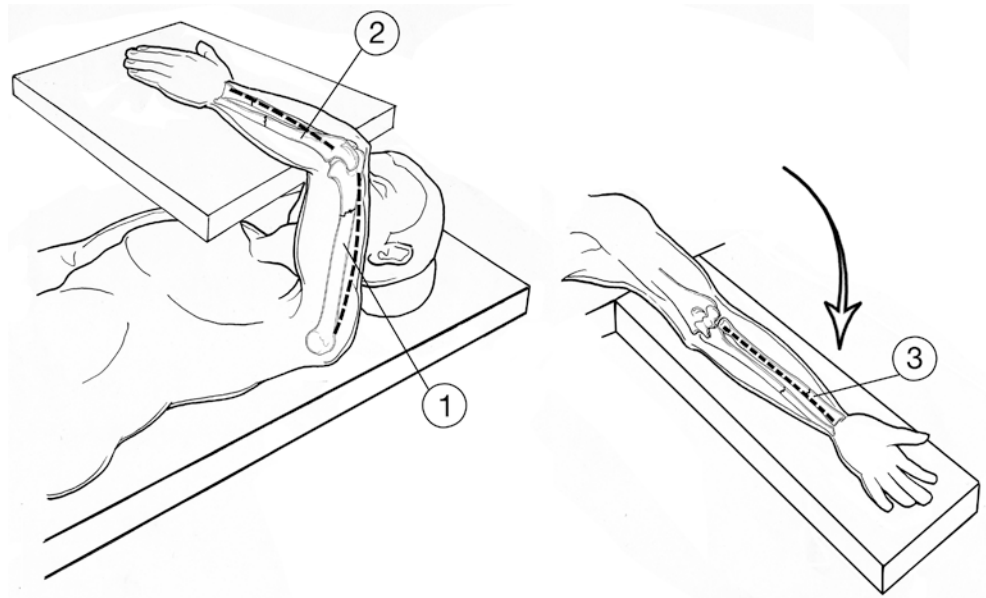
For radial fractures at any level, the patient is supine (Fig. 22.3). ORIF of the radius is performed anteriorly, then the elbow is flexed for fixation of the ulna via a subcutaneous border approach. For ORIF of the distal humerus, place the arm on Mayo stand across the chest (posterior approach).

**Fig. 22.3** Supine position with option for arm across chest

An alternative method is to first perform ORIF of the humerus and the ulna, then the radius (Fig. 22.4). The bottom line is that you must be flexible with your approach and

think through the sequences before you position the patient and put knife to skin.

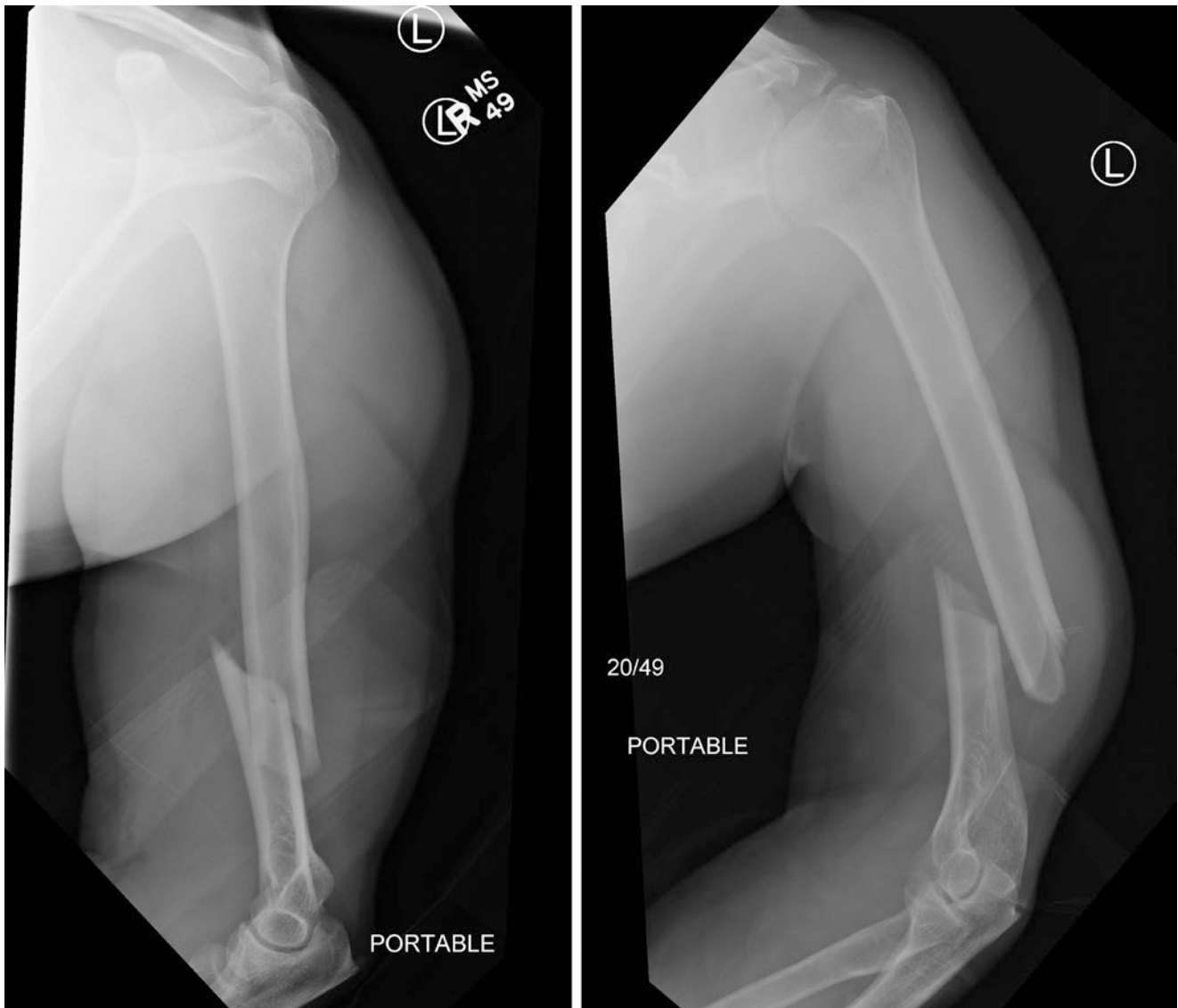
**Fig. 22.4** Supine position with arm across chest, followed by arm extended



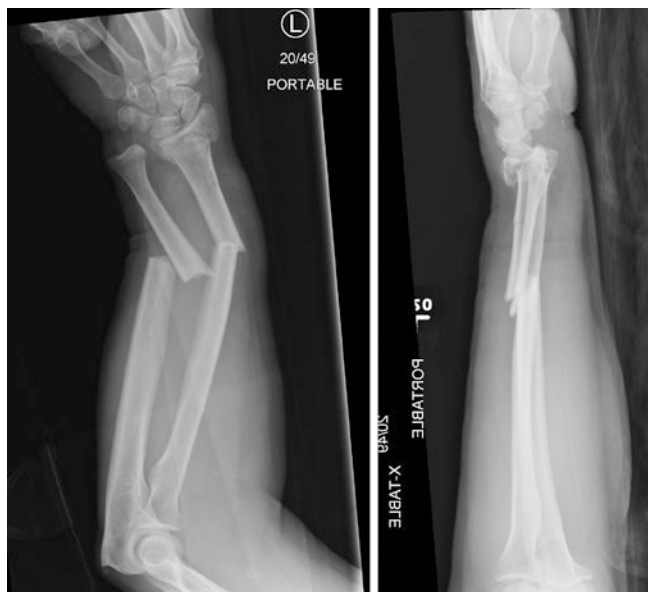
If the fracture pattern of the humerus affords adequate fixation, I use four screws (eight cortices at least) and radial/ulnar screws (six cortices at least). I prefer four screws and eight cortices placed proximal and distal to the fracture, using small fragment plates. I also use large fragment, narrow plates for the humerus in larger patients. Intramedullary

(IM) nail fixation is an option, particularly for the ulna and humerus, but I prefer ORIF for all three fractures (Figs. 22.5, 22.6, 22.7, 22.8, 22.9, 22.10, 22.11, 22.12, 22.13, 22.14, 22.15, 22.16, 22.17, 22.18, 22.19, 22.20, 22.21, 22.22, 22.23, 22.24, 22.25, 22.26, 22.27, 22.28, 22.29, 22.30, 22.31, 22.32, 22.33, 22.34, 22.35, 22.36, and 22.37).





**Fig. 22.5** Injury radiographs of left humerus



**Fig. 22.6** Injury radiographs of left radius, ulna shaft, and distal radius fracture



**Fig. 22.7** Traction radiographs of left distal radius fracture

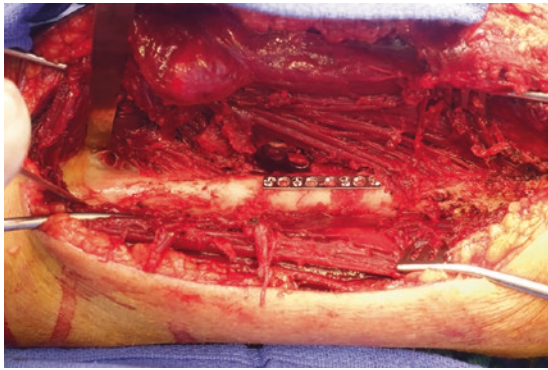


**Fig. 22.8** Incisions outlined for anterolateral humerus and radial shaft and distal radius approach

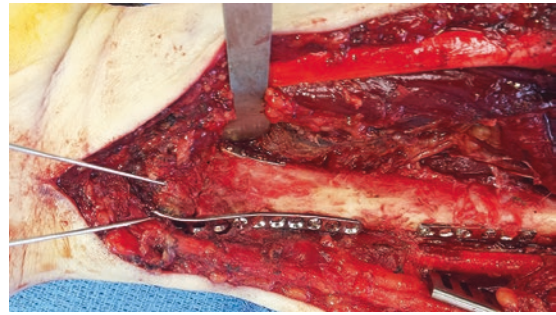


**Fig. 22.9** Dorsal ulna incision outlined

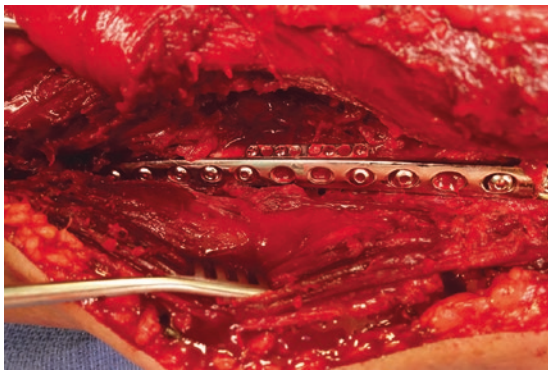




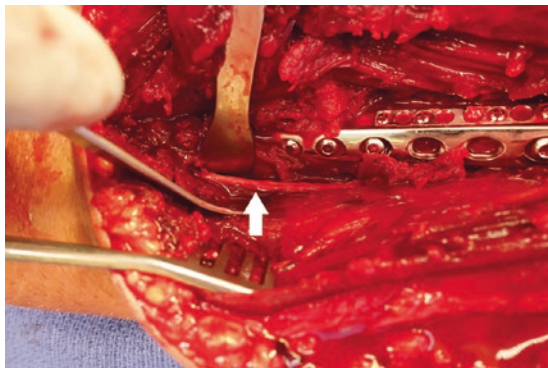
**Fig. 22.10** Provisional mini-fragment plate fixation of the humerus



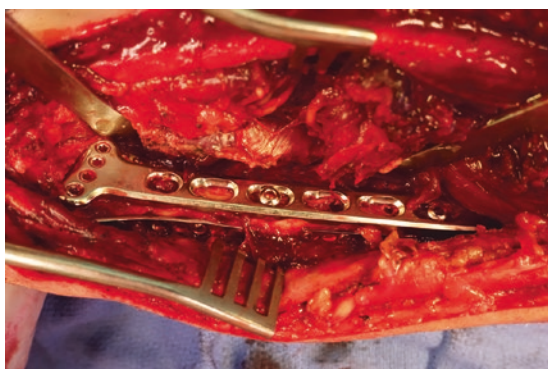
**Fig. 22.11** Provisional plate fixation of a distal radius fracture and radial shaft fracture. The plating sequence is radius provisional, humerus provisional, definitive humerus, ulna, and then radius



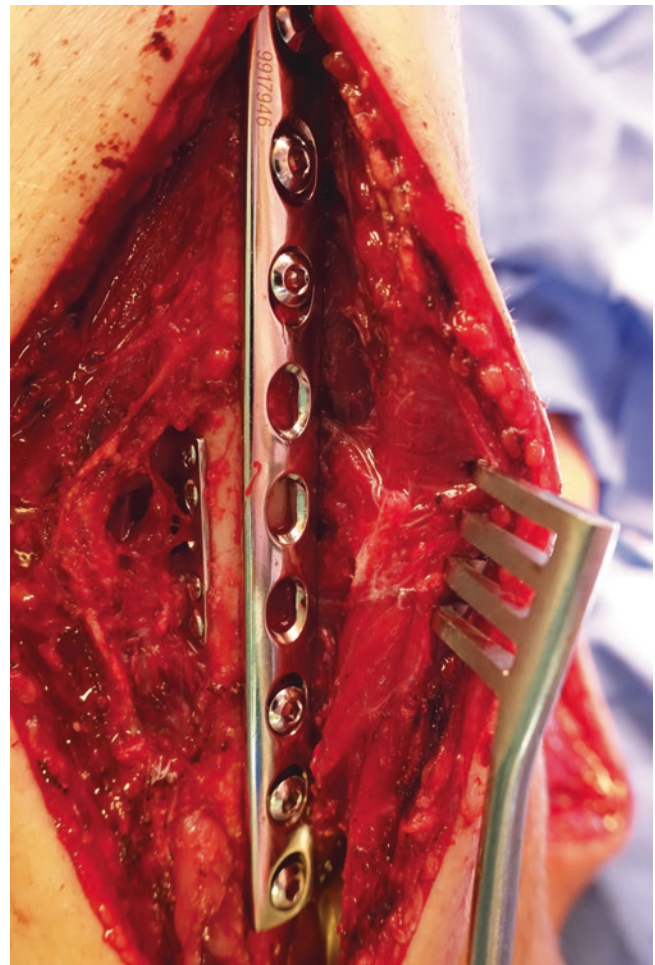
**Fig. 22.12** Definitive fixation of the humerus



**Fig. 22.13** Relationship of the radial nerve to anterolateral fixation (*arrow*)

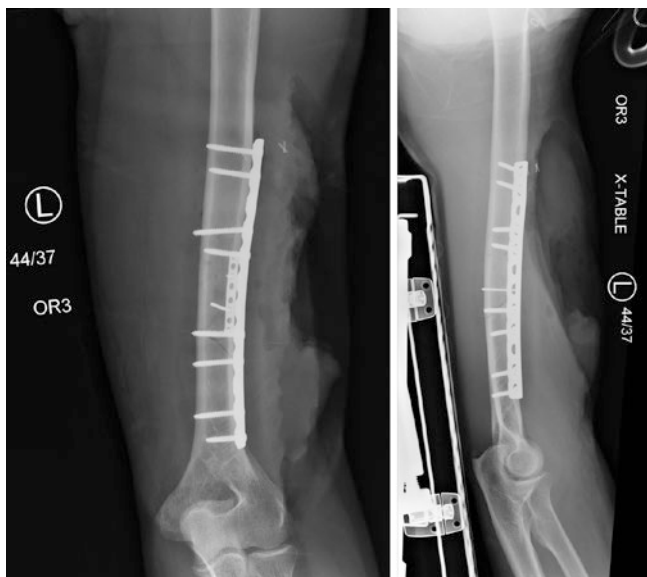


**Fig. 22.14** Definitive fixation of radial shaft and distal radius fracture, showing mini-plate fixation



**Fig. 22.15** Definitive fixation of ulna with provisional plate fixation

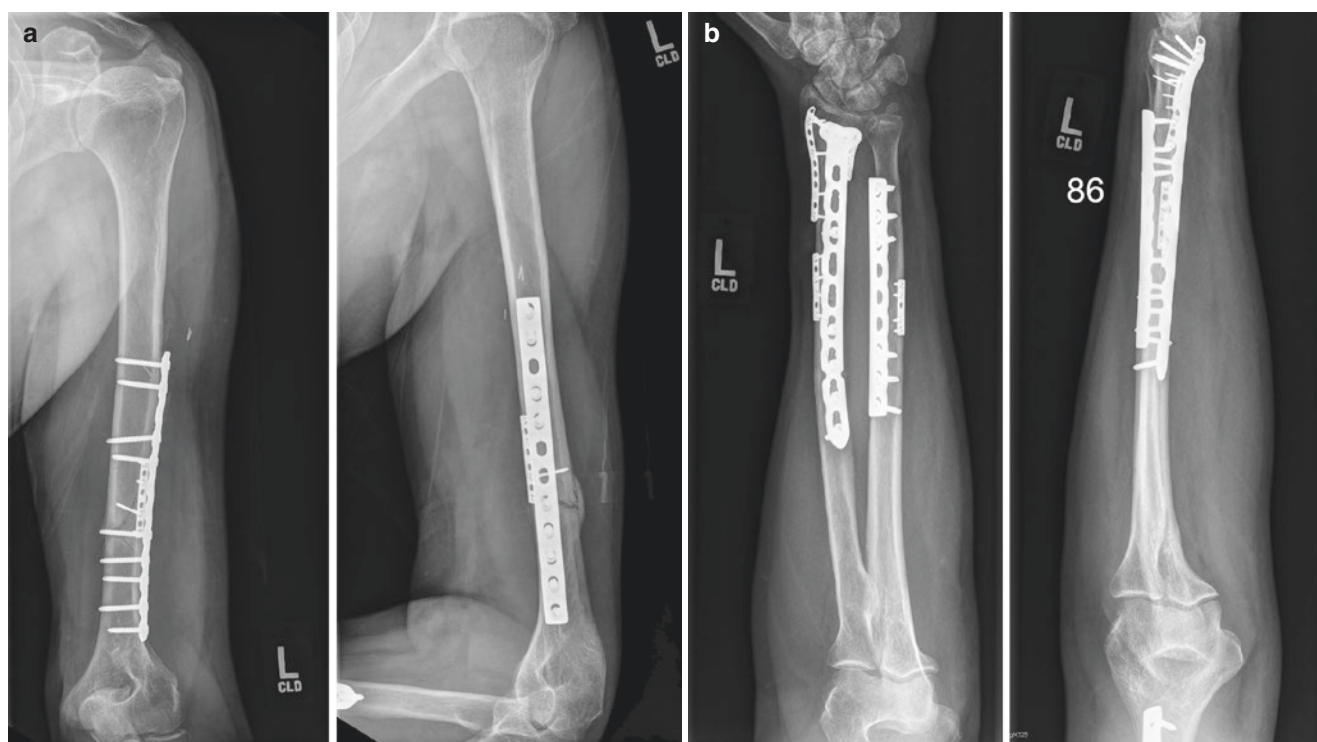




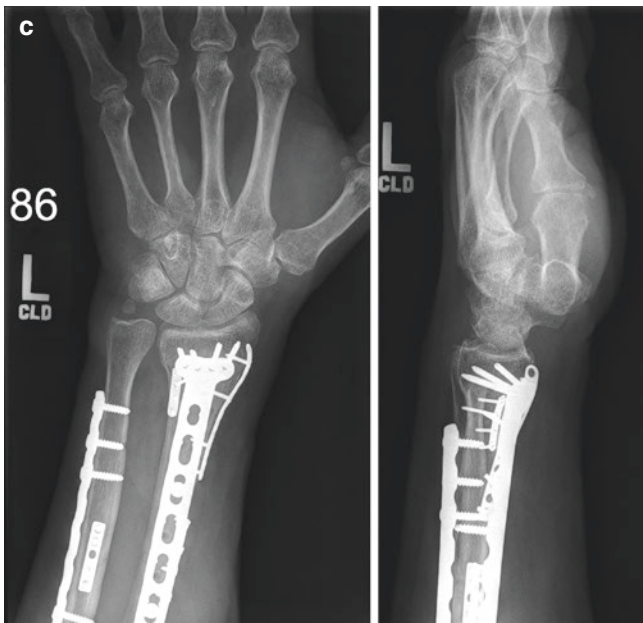
**Fig. 22.16** Intraoperative radiograph of left humerus following open reduction and internal fixation (ORIF)



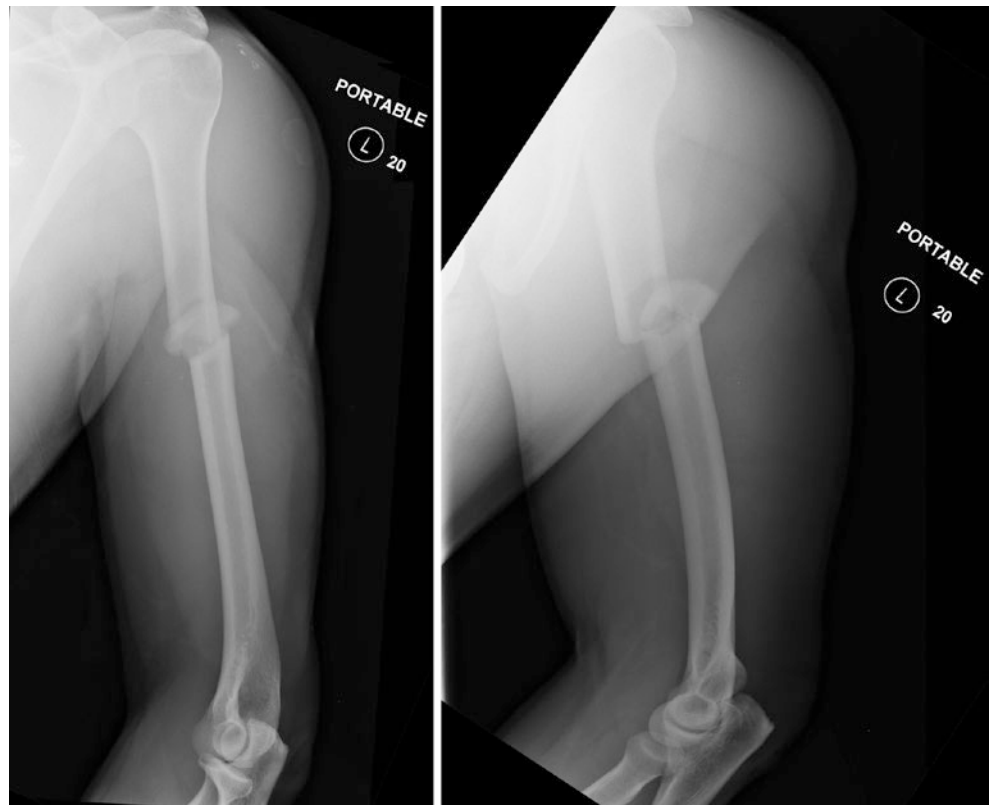
**Fig. 22.17** Intraoperative radiograph of radius, ulna, and distal radius following ORIF



**Fig. 22.18** (a–c) Follow-up radiographs of humerus, radius and ulna, and distal radius



**Fig. 22.18** (continued)



**Fig. 22.19** Injury radiographs of left humerus fracture



**Fig. 22.20** Injury radiographs of left radius and ulna shaft fractures



**Fig. 22.21** Incision for approach to left humerus and radius



**Fig. 22.22** Incision for left ulna with subsequent fixation; the sequence is radius, ulna, and then humerus



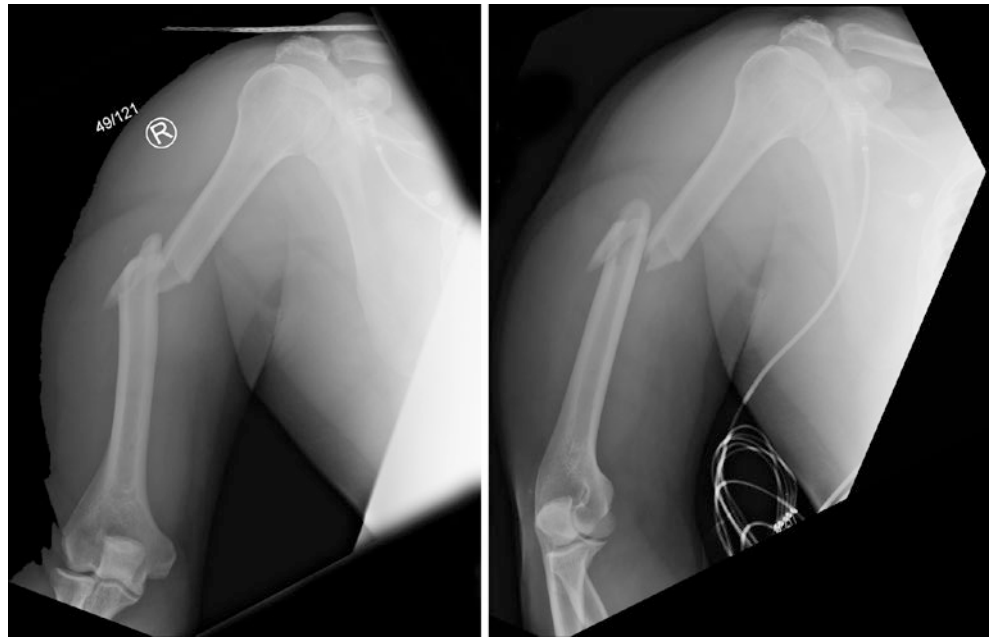
**Fig. 22.23** Intraoperative radiograph of left proximal humerus shaft ORIF



**Fig. 22.24** Intraoperative radiographs of left radius and ulna shaft fractures following ORIF



**Fig. 22.25** Injury radiographs of right humerus fracture



**Fig. 22.26** Injury radiographs of right radius and ulna fractures



**Fig. 22.27** Incision for anterolateral humerus and radial shaft fracture



**Fig. 22.28** Incision for ulna; procedure sequence of approaches begins with debridements because of open fractures, followed by fixation of the radius, then the ulna, then the humerus



**Fig. 22.29** Radiographs of right humerus following ORIF



**Fig. 22.30** Radiographs of right radius and ulna fracture following ORIF



**Fig. 22.31** Injury radiographs of left humerus fracture in splint



**Fig. 22.32** Injury radiographs of left radius and ulna shaft fractures in splint



**Fig. 22.33** Radiographs of left humerus following ORIF; the sequence began with the humerus via the posterior approach, then the ulna, then the radius with the patient supine because of multi-system injuries





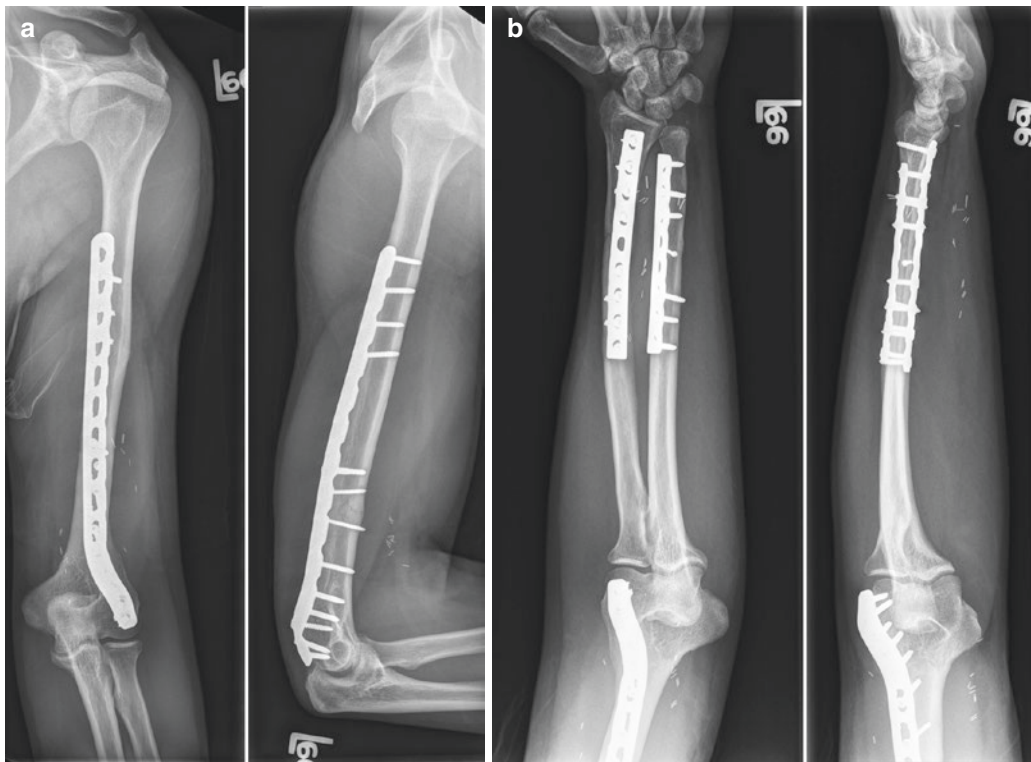
**Fig. 22.34** Radiographs of left radius and ulna following ORIF



**Fig. 22.35** Injury radiographs of left distal humerus fracture



**Fig. 22.36** Injury radiographs of left radius and ulna shaft fractures



**Fig. 22.37** (a) Radiographs following ORIF of the left humerus, radius, and ulna in sequence of radius and ulna first, then the humerus, performed with the patient supine. (b) Radiographs following ORIF of the left humerus, radius, and ulna in sequence of radius and ulna first, then humerus

### 22.3 Patient Rehabilitation

I allow immediate full range of motion and weight-bearing. Patients with peripheral nerve injuries are not permitted weight-bearing for 6 weeks because of the loss of dynamic stabilization and proprioceptive feedback, which are essential in weight-bearing.

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### 23.1 Radial Shaft Fractures with Distal Radioulnar Joint Dislocation

Eponyms unfortunately are pervasive and frequently unhelpful in facilitating care rendered to patients. The term *Galeazzi fracture* may be one exception [1]. When the somnolent sur-

geon gets a call in the middle of the night from the resident, reporting that a patient has a Galeazzi fracture, both know that there is a radial shaft fracture with dislocation of the distal radioulnar joint (DRUJ) (Fig. 23.1).





**Fig. 23.1** Injury radiographs of right forearm Galeazzi fracture with significant radial shortening

Both the surgeon and the resident also know that open reduction internal fixation (ORIF) of the shaft will be performed, usually with closed reduction of the DRUJ. The DRUJ stability will be evaluated, but rarely is there a need for any form of surgical stabilization, such as ligamentous repair or ulnar styloid fixation. Usually the patient is placed in supination to maintain the DRUJ reduction. From that time on, issues abound.

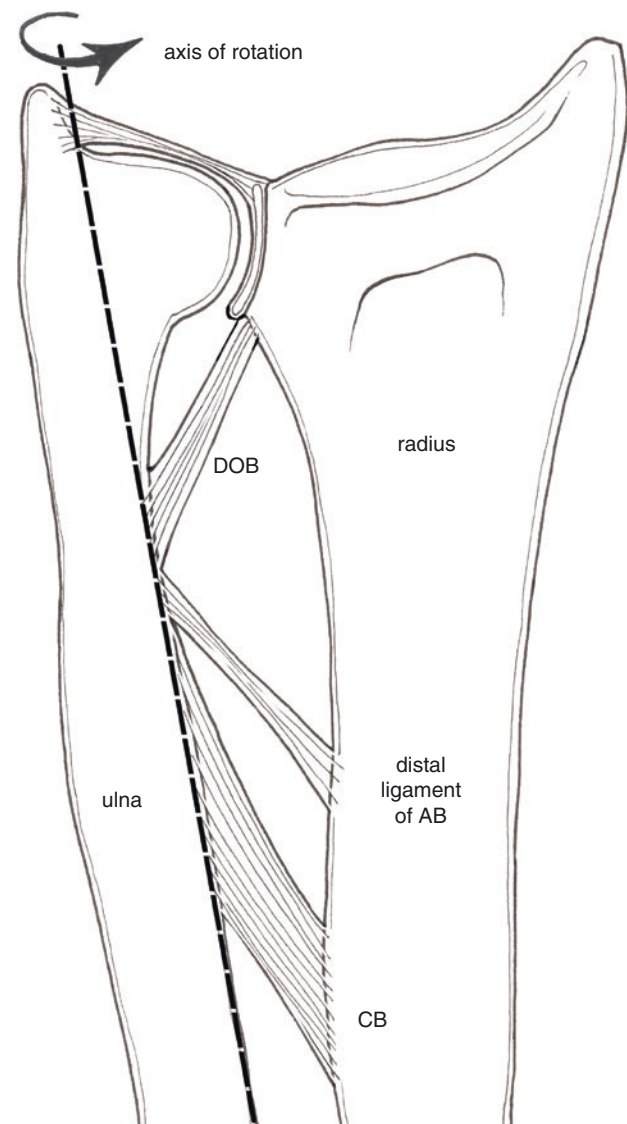
One of the first questions to arise is “What defines a Galeazzi fracture?” Ring *et al.* [2] declare that Galeazzi fractures are less common than isolated radius fractures, but this begs the question “Does a radial shaft fracture occur in isolation?” There probably is a spectrum of radius fractures, among which the Galeazzi fracture fits in. Studies performed over the years have looked at the DRUJ in forearm fractures. Goldberg *et al.* [3] performed a radionuclide study that found increased uptake at the DRUJ in isolated fractures of the radius, the ulna, or both bones, implying some form of DRUJ injury. Mikić [1] also performed evaluations using an arthrogram to evaluate the status of the triangular fibrocartilage complex (TFCC) articular disc and found disruption in Galeazzi fractures with DRUJ dislocation. Finally, MRI studies have been done in attempts to correlate Galeazzi fractures with pathology at the DRUJ [4]. Such findings invite a question, “Does pathology at the DRUJ require intervention or correlate with any subsequent long-term results?” One of the first classic articles on this topic was a review of radial shaft fractures by Hughston [5]; whether these fractures were defined as Galeazzi or isolated radial shaft fractures is unclear, but when unfixed, 92% had an unsatisfactory result. The impact of the DRUJ status was difficult to tease out in this report, so it is unclear whether the unsatisfactory results were DRUJ-related. Mikić [1], in a large study of radial shaft fractures in adults, also found that without internal fixation of the radius, there was an 80% incidence of poor results. Again, the impact of the DRUJ is unclear, but these articles do reinforce the need for radial shaft fixation.

### 23.1.1 Evaluating DRUJ Separation and Associated Soft Tissue Injury

Studies have attempted to evaluate the degree of DRUJ separation or displacement and DRUJ-associated soft tissue injury. Mikić [1] stated that 5 mm of radial shortening defines a Galeazzi fracture. Moore *et al.* [6] performed cadaver studies to evaluate the DRUJ relationship, and found that with a radius osteotomy, 5 mm of shortening could occur without any stabilizing structure division. At 5–10 mm, either the

TFCC or the interosseous membrane division resulted in instability. Division of both was required to produce 10 mm or more of instability.

To determine the degree of instability, a radiograph of the opposite side should be obtained to establish the starting point of the ulnar variance. The importance of the interosseous membrane (IOM) on DRUJ stability is emphasized with the contribution of the distal oblique bundle (DOB). The DOB is a thickened component of the IOM, running from the ulna shaft distally to an insertion in the inferior aspect of the sigmoid notch (Fig. 23.2). The DOB is present in 40% of specimens studied [7].



**Fig. 23.2** Interosseous ligament bands, including the distal oblique band (DOB)

### 23.1.2 DRUJ Instability with Ulnar Styloid Fracture

Even if we can define the degree of shortening present and how this may correlate to soft tissue injury, the presumption is that once the radius is stabilized, the DRUJ will be evaluated for stability. I find evaluation can be difficult, using either the number of millimeters of displacement or pathologic findings such as a click or clunk in either neutral or supinated position. If there is instability and an ulnar styloid fracture is present and of adequate size, I consider stabilization of the ulnar styloid. There may be pathology, such as tears to the TFCC or DRUJ ligament disruption; in the face of an ulnar styloid fracture, fixation alone may not provide stability. As shown by Ruch *et al.* [8], placement of a distal radius fracture in supination, with an unstable DRUJ, has better outcome with external fixation than with purely ulnar styloid fixation. Rettig and Raskin [9] defined Type I fractures as being within 7.5 cm from articular surface to fracture, and approximately 50% of these cases underwent some form of DRUJ stabilization, either pin fixation or ligament repair. These reports reflect the difficulty in establishing what is in fact stability of the DRUJ.

### 23.2 Treatment: Immobilization Versus Fixation

Immobilization in supination, as initially put forth by Moore *et al.* [10] for about 4 weeks of mobilization had been recommended. Gwinn *et al.* [11] subsequently reviewed a series of Galeazzi fractures without DRUJ stabilization and implemented a regimen of 2 weeks' immobilization in full supina-

tion and a Munster brace with allowance of elbow range of motion, which was followed by 2 weeks of neutral- to full supination range of motion, followed by unrestricted activity. A similar project evaluated immobilization in neutral versus supination and found no difference in subsequent long-term consequences and functional results [12].

Therefore I feel that very rarely does one need to address the DRUJ once reduction is confirmed radiographically, unless there is profound instability that could be addressed with ulnar styloid fixation or ligamentous repair. A disclaimer to this approach is the open fracture with significant soft tissue injury in the area of the distal ulna that allows access for soft tissue repair, either through the open fracture or with ORIF of the ulnar styloid. Also, some form of intervention for the DRUJ would be considered in a patient mandated for any reason to a pronated position. With that said, the first step would be radius fixation. Patient positioning, prepping, and draping are presented in Chap. 21.

### 23.3 Approach to Radial Shaft Fixation

The approach and interval I use for radial shaft fixation is similar to that discussed for the radial and ulnar shafts. I use an interval between the flexor carpi radialis (FCR) and the brachioradialis with maintenance of the radial artery ulnarly. I feel that the approach to any radial shaft fracture between the radial neck and the distal metadiaphyseal region should be an anterior approach (Figs. 23.3, 23.4, 23.5, 23.6, 23.7, and 23.8); a dorsal approach is required only when there is an intraarticular component to the radial head or distal radius fracture that requires ORIF.

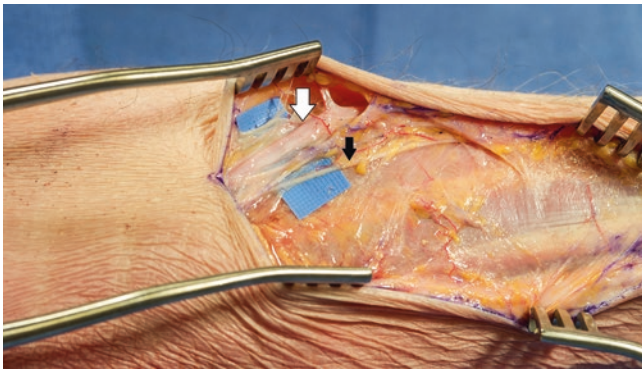


**Fig. 23.3** Incision outlined for left radial shaft open reduction and internal fixation (ORIF)

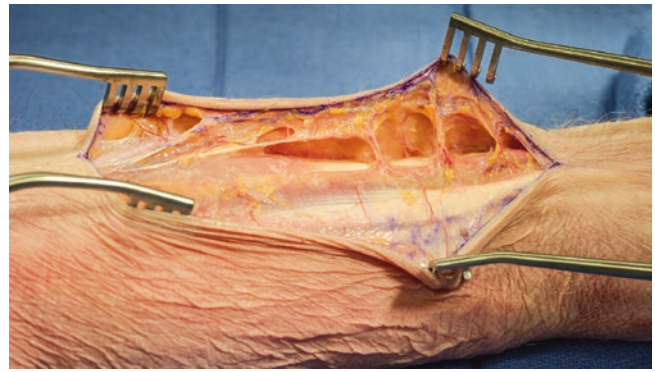


**Fig. 23.4** Skin incision performed to level of forearm fascia

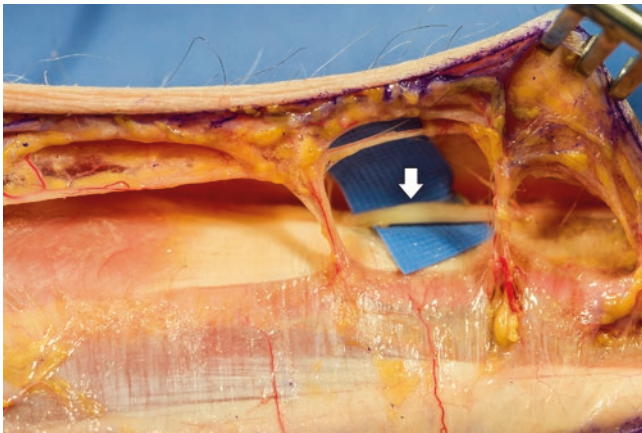




**Fig. 23.5** Lateral antebrachial cutaneous nerve (*black arrow*) and cephalic vein (*white arrow*)



**Fig. 23.6** Perforators from the radial artery to the radial skin flap



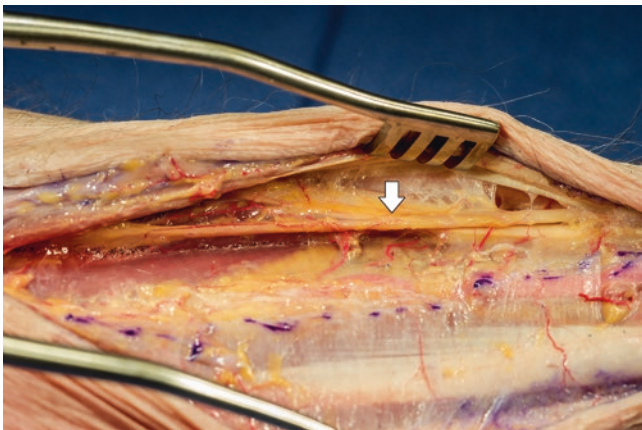
**Fig. 23.7** Radial dorsal sensory nerve (*arrow*) exiting between the brachioradialis (BR) and extensor carpi radialis longus



**Fig. 23.8** Fascial incision along the BR, with the radial artery to be maintained ulnarly and not circumferentially dissected

I thus have very little, if any, use for the Boyd-Thompson dorsal approach to the shaft. The interval is developed

between the radial artery and the superficial branch of the radial nerve (SBRN) (Figs. 23.9 and 23.10).



**Fig. 23.9** Dorsal sensory nerve (*arrow*)

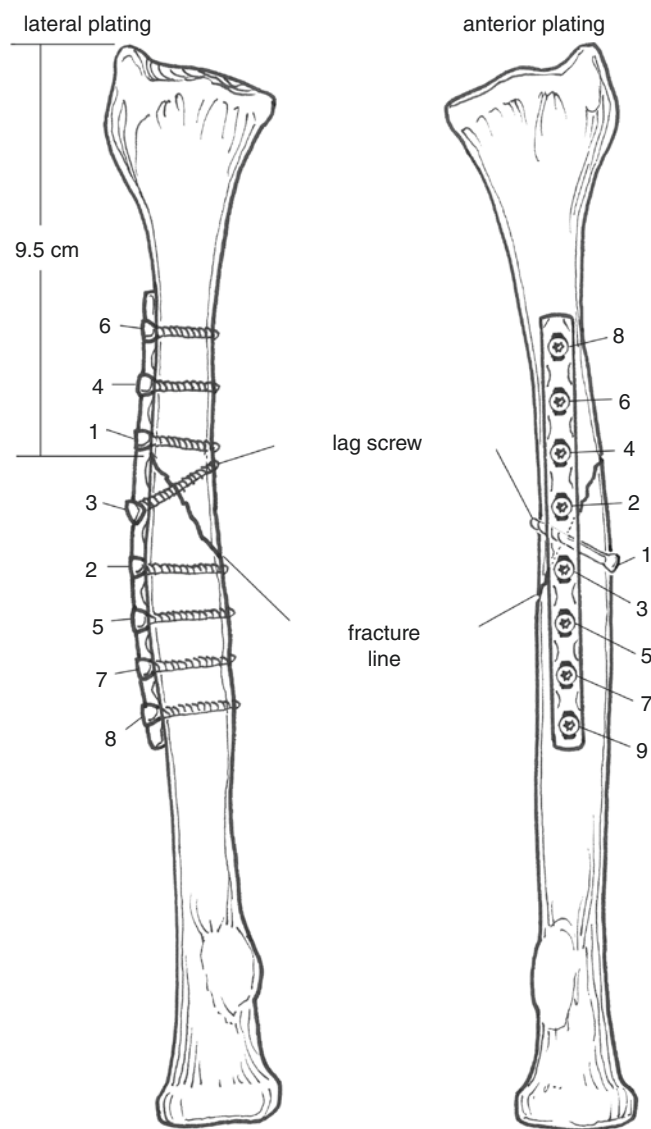


**Fig. 23.10** Interval between BR and dorsal sensory nerve radially and radial artery ulnarly

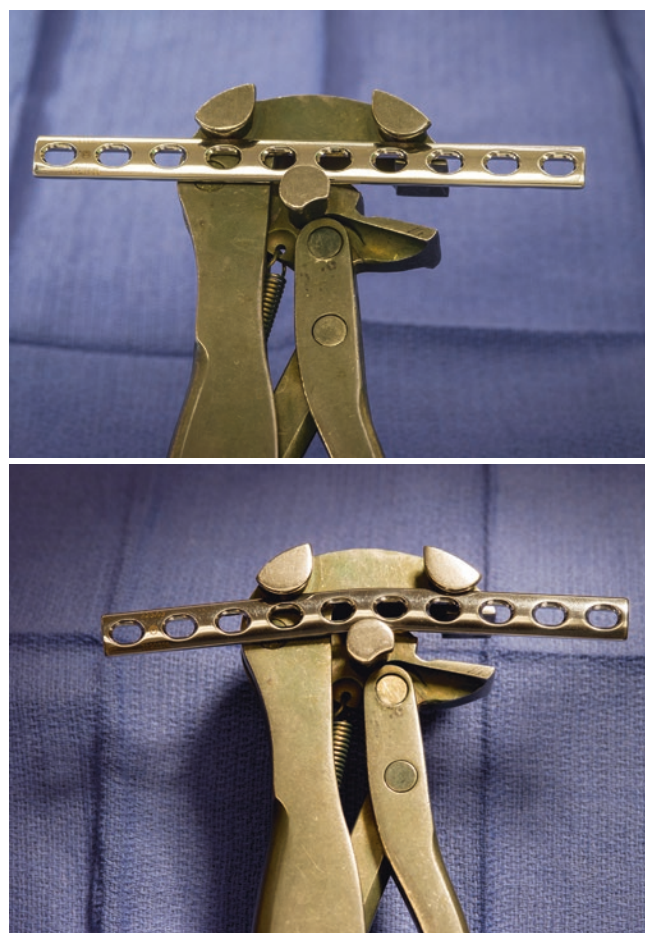
## 23.4 Fixation

If the level of the fracture is in the distal half, the pronator teres remains with its insertion intact. If the fracture falls proximal to the middle of the radius, then the pronator teres is elevated. The plating is generally anterior. Controversy has arisen concerning the orientation of the plate. The biomechanical aspects of this plating were reviewed by Eglseder *et al.* [13]. An oblique osteotomy

pattern was designed with either a lag screw and anterior plating of the radius or plating radially with a lag through the plate (Fig. 23.11). It was found that the plate fixation has similar biomechanical characteristics whether the plate is placed anteriorly or radially. I prefer the anterior approach, because I believe there are fewer problems related to soft tissues (Figs. 23.12, 23.13, 23.14, 23.15, 23.16, 23.17, 23.18, 23.19, 23.20, 23.21, and 23.22).

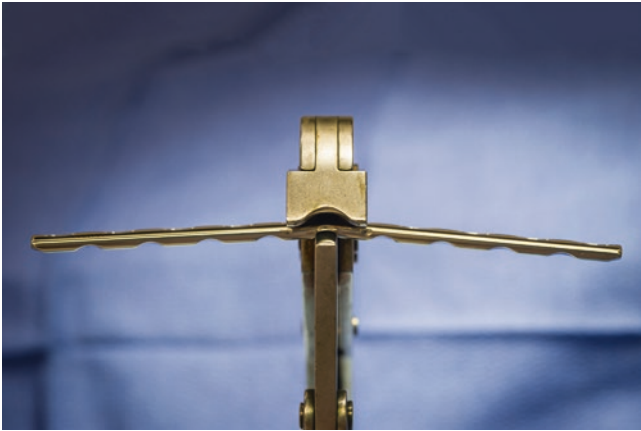


**Fig. 23.11** Options for plate and screw position for radius fracture fixation and screw insertion sequence

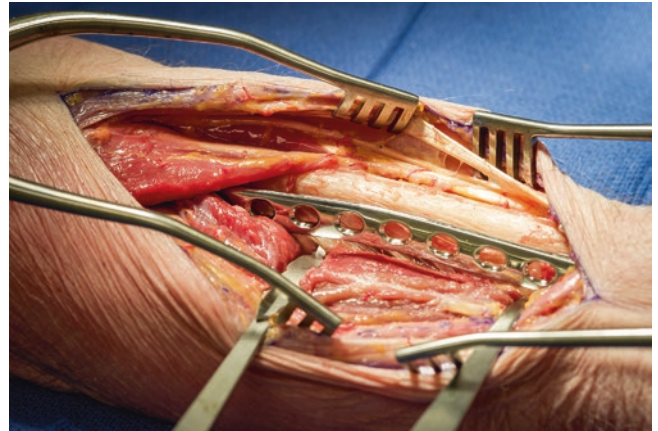


**Fig. 23.12** Coronal bend in plate for radial bow

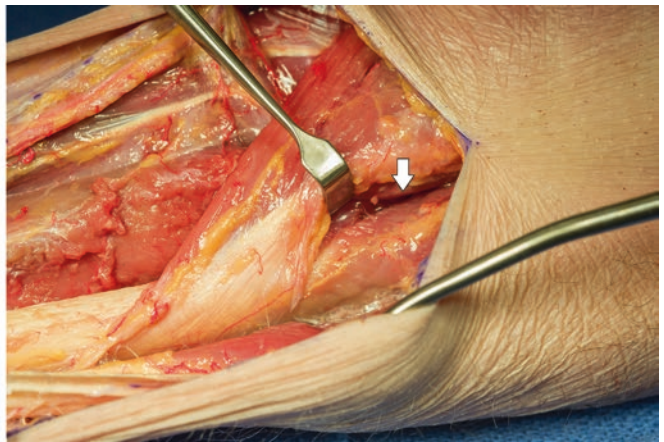
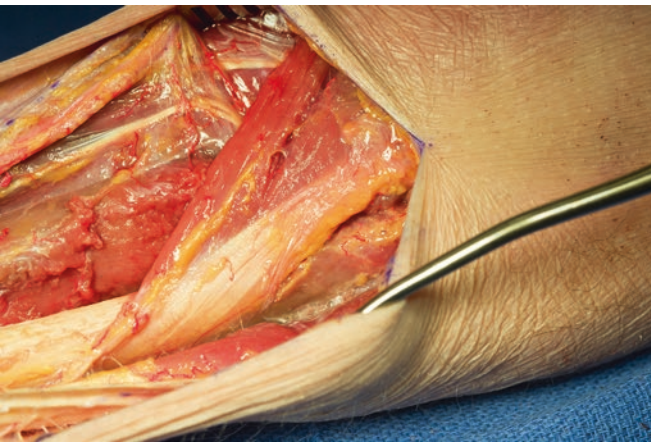




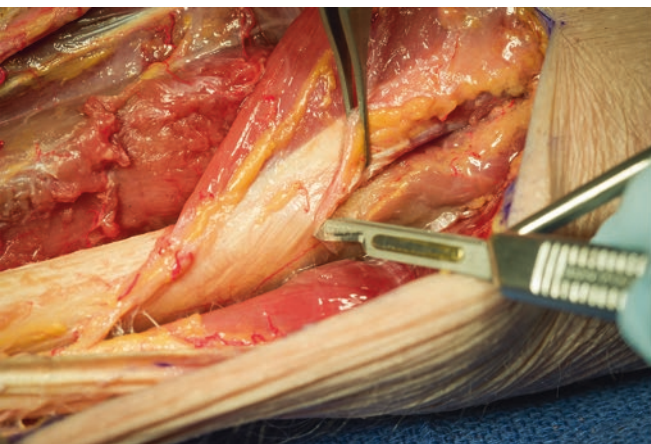
**Fig. 23.13** Acute bend for pre-stress to prevent gapping at far side of fracture



**Fig. 23.14** Position of plate between the pronator teres (PT) and the flexor digitorum superficialis and flexor pollicis longus

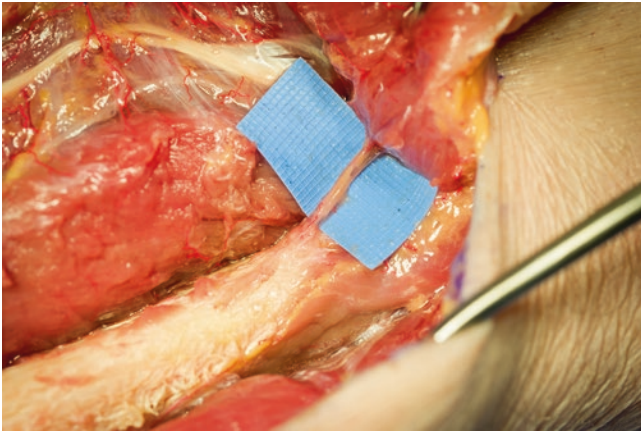


**Fig. 23.15** Elevation of PT insertion for proximal fractures. Proximal interval between PT and supinator (*arrow*)



**Fig. 23.16** Elevation should be in an acute angle to prevent feathering when elevating from the obtuse angle

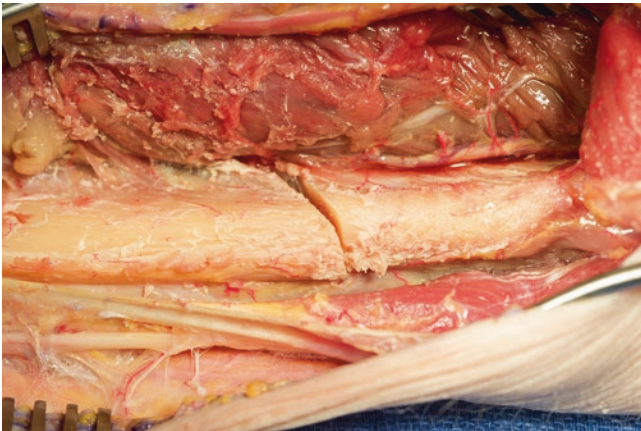




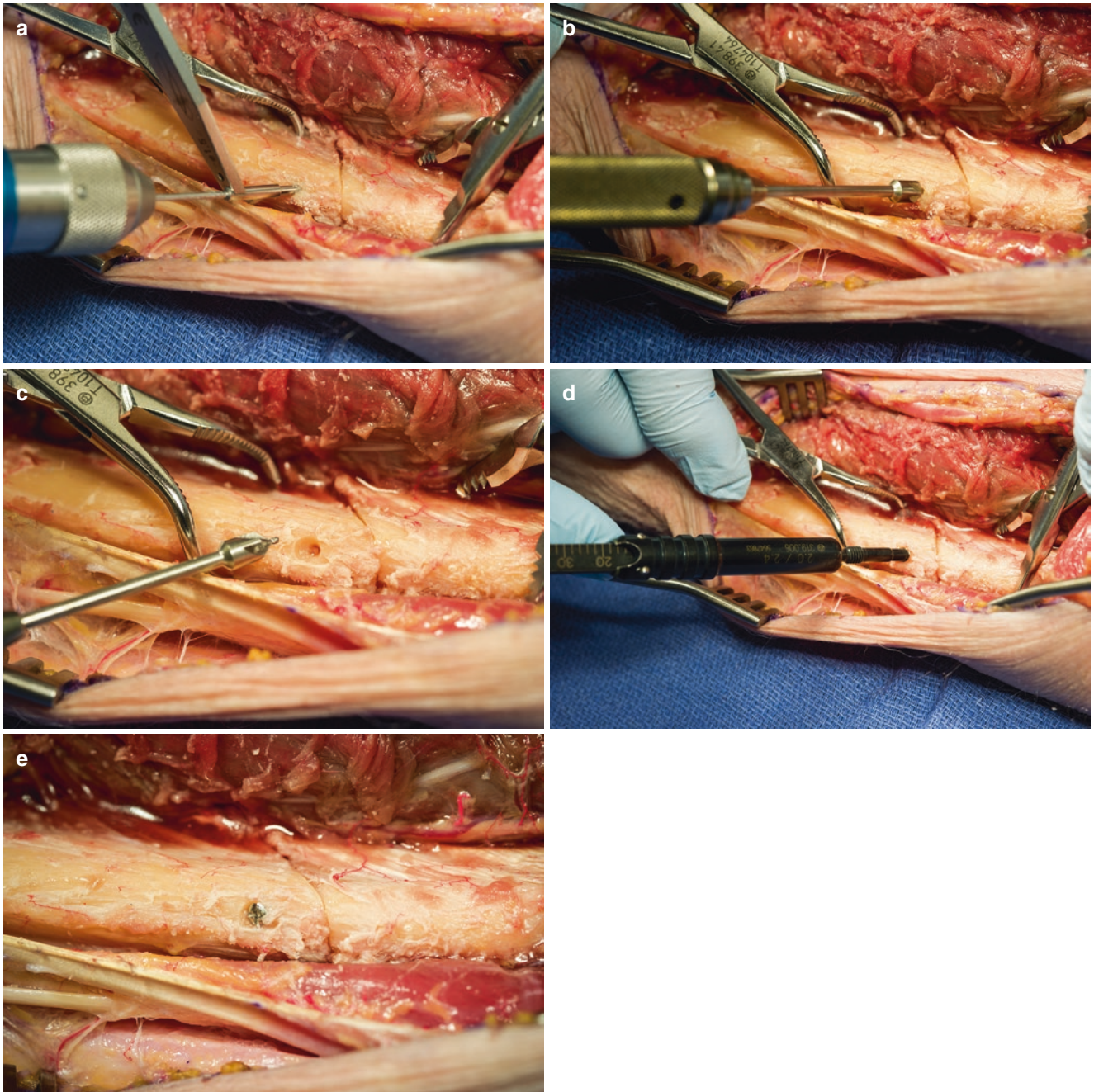
**Fig. 23.17** A nutrient vessel can be seen at the proximal mid third of the radius. (This vessel's channel looks like a fracture and may get you ER calls at three in the morning.)



**Fig. 23.18** Plate positioned anteriorly (looking over the forearm from the ulnar vantage point)

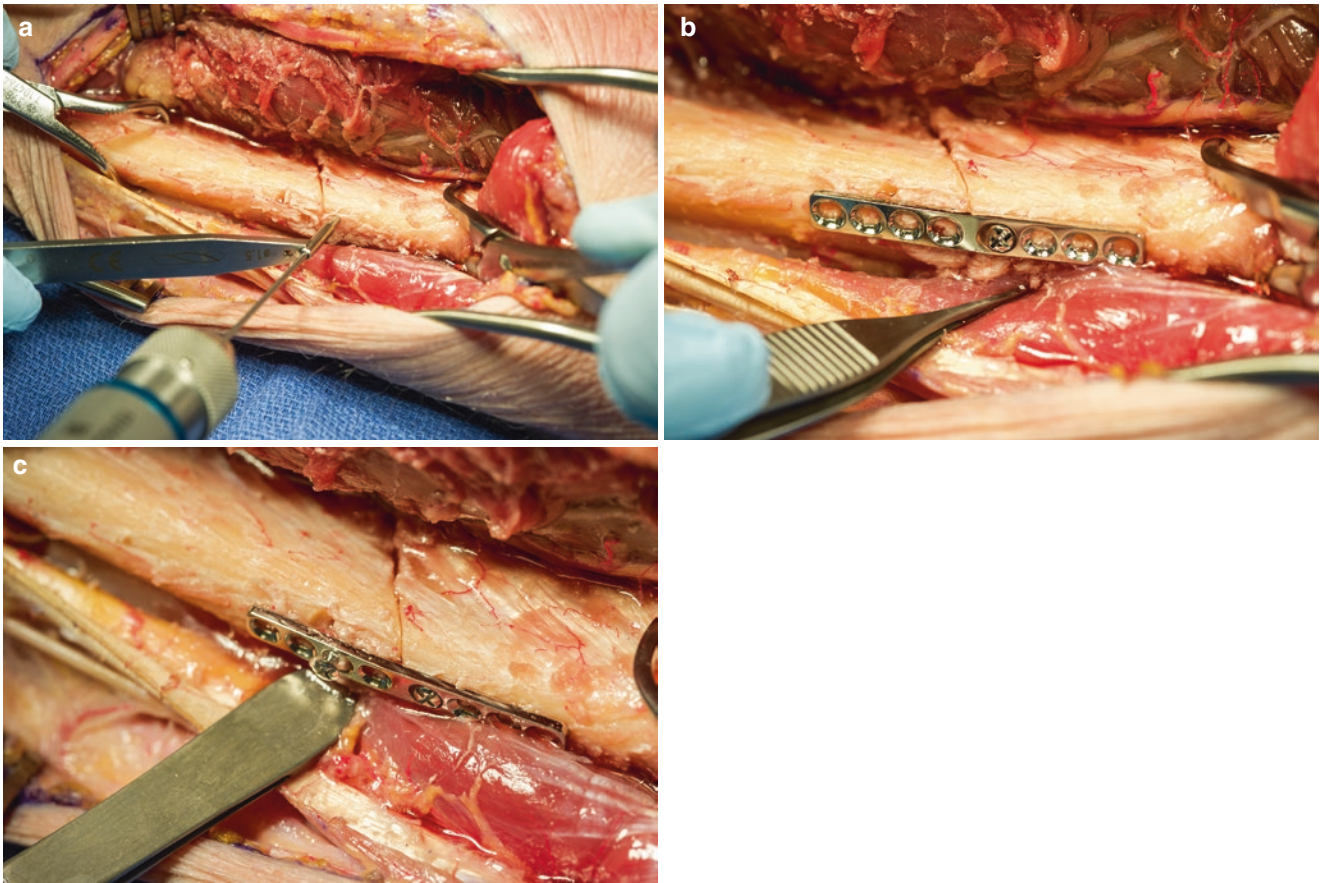


**Fig. 23.19** Osteotomy/fracture created (looking from the radial vantage point)



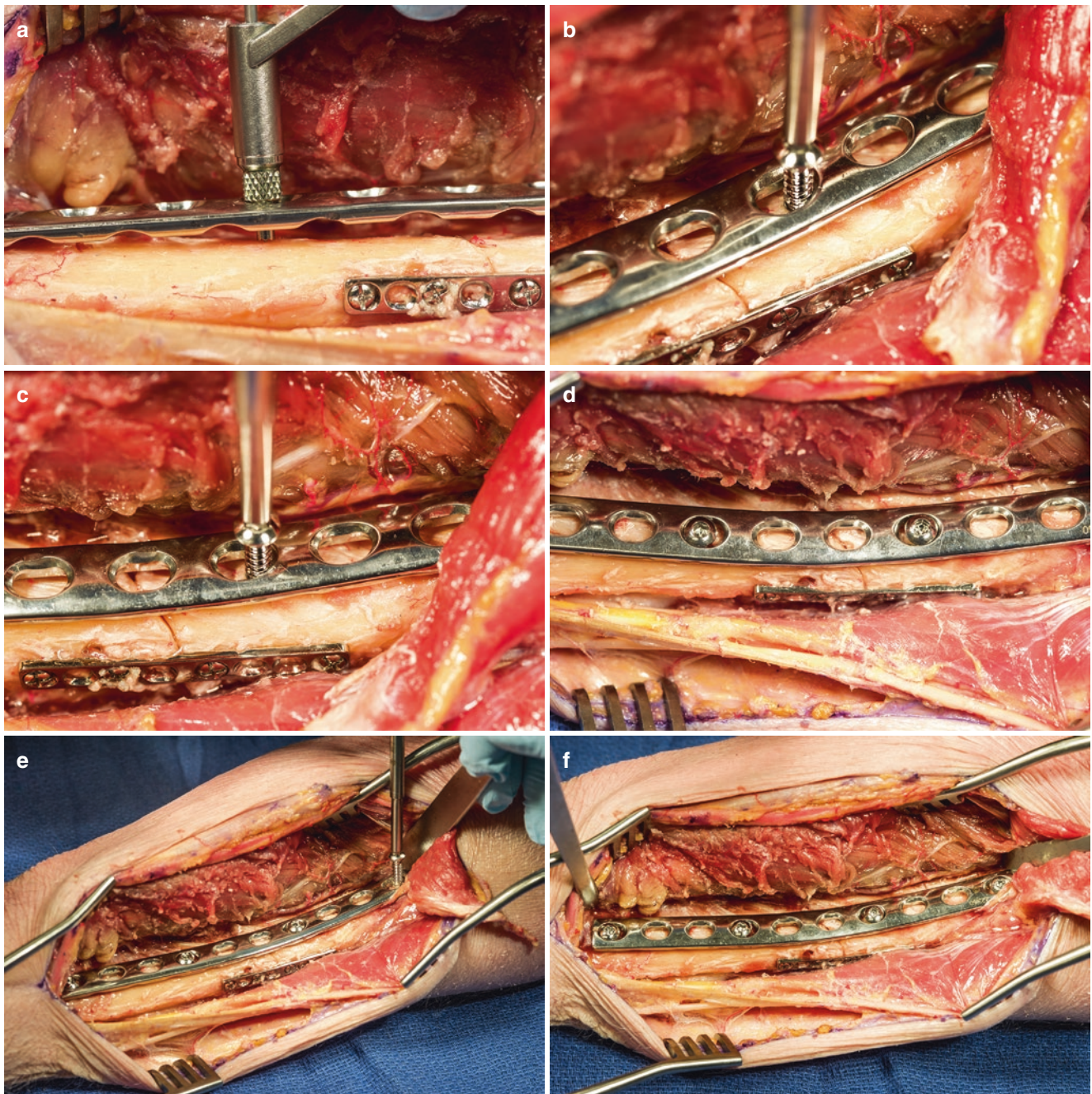
**Fig. 23.20** (a) Lag screw insertion for provisional fixation following reduction, using 2.0-mm screw pilot hole with a 1.5-mm drill bit; glide hole with 2.0-mm drill bit. (b) Countersink. (c) Countersinking completed. (d) Measure, usually 16–18 mm. (e) Screw inserted





**Fig. 23.21** (a) A 2.0-mm mini plate can be used for provisional fixation if needed, with pre-drilling of a hole. (b) Plate and screw positioned to create an axilla for compression. (c) Eccentrically load compression screw





**Fig. 23.22** (a) Definitive plating with 3.5-mm LC-DCP. (b) Compression screw insertion. (Yes, you can compress with the mini plate in place.) (c) Compression screw insertion. (d) Two inboard

screws inserted and seated. (e) Remaining screws inserted. (f) Inboard and outboard screws inserted. (Two more screws proximally and distally would be used clinically.)

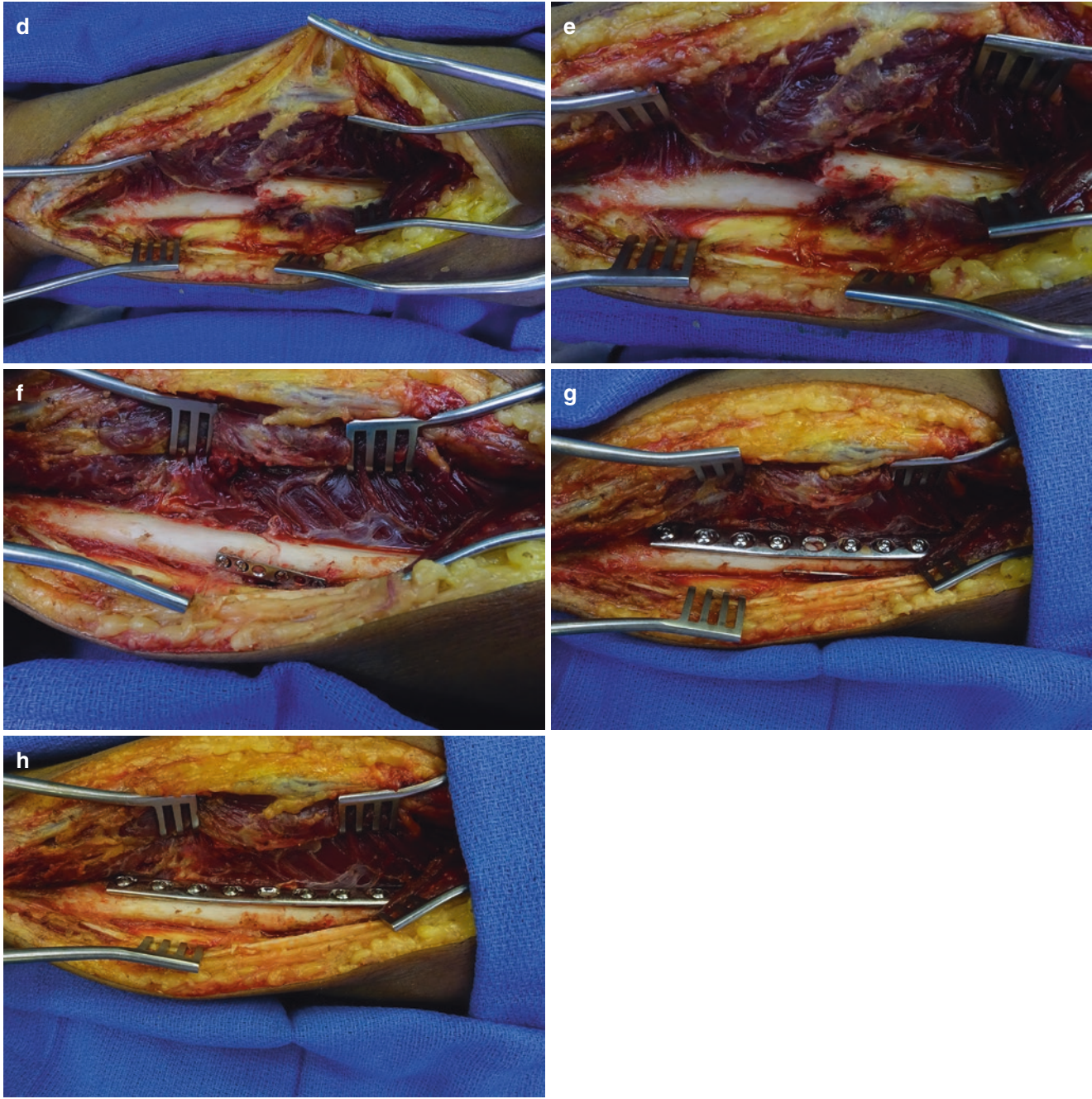
Plating radially requires more elevation of the brachioradialis; this impacts the SBRN and may cause tendon irritation, particularly to the extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis (ECRB). I prefer to use

four screws proximal and distal to the fracture, usually with a 10-hole, 3.5-mm limited-contact dynamic compression (LCDC) plate (Fig. 23.23).

**Fig. 23.23** (a–c) Injury radiographs of left forearm Galeazzi fracture. (d) Anterior approach to left radius fracture. (e) Fracture exposed. (f) Provisional fixation with 2.0-mm mini-fragment plate. (g) Completed fixation with 3.5-mm limited-contact dynamic compression plate (LC-DCP). (h) Provisional plate removed. (i) and (j), Final radiographs







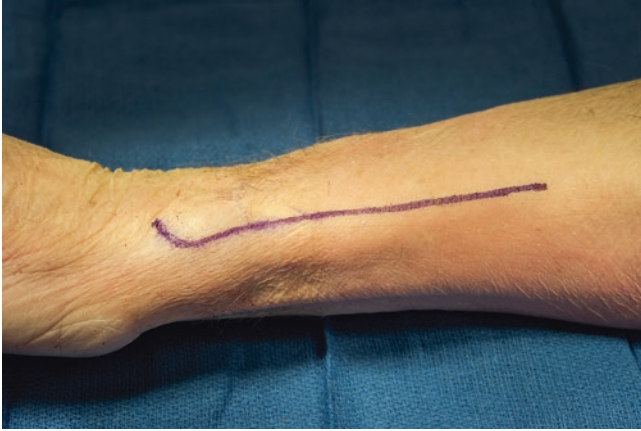
**Fig. 23.23** (continued)



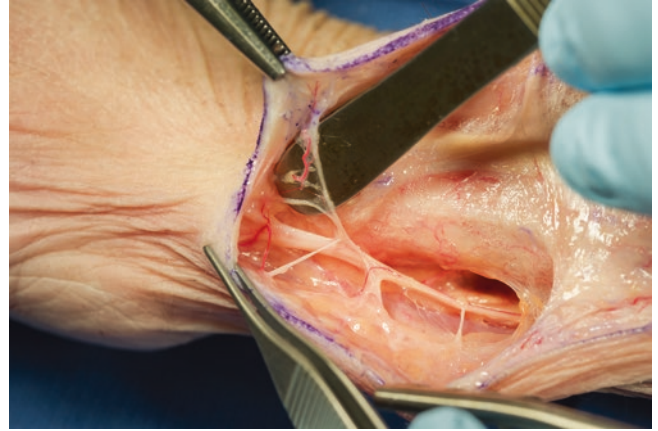
**Fig. 23.23** (continued)



If the ulnar styloid is to be stabilized, I use a J-incision over the head of the ulna, with the J curving dorsally (Figs. 23.24 and 23.25).



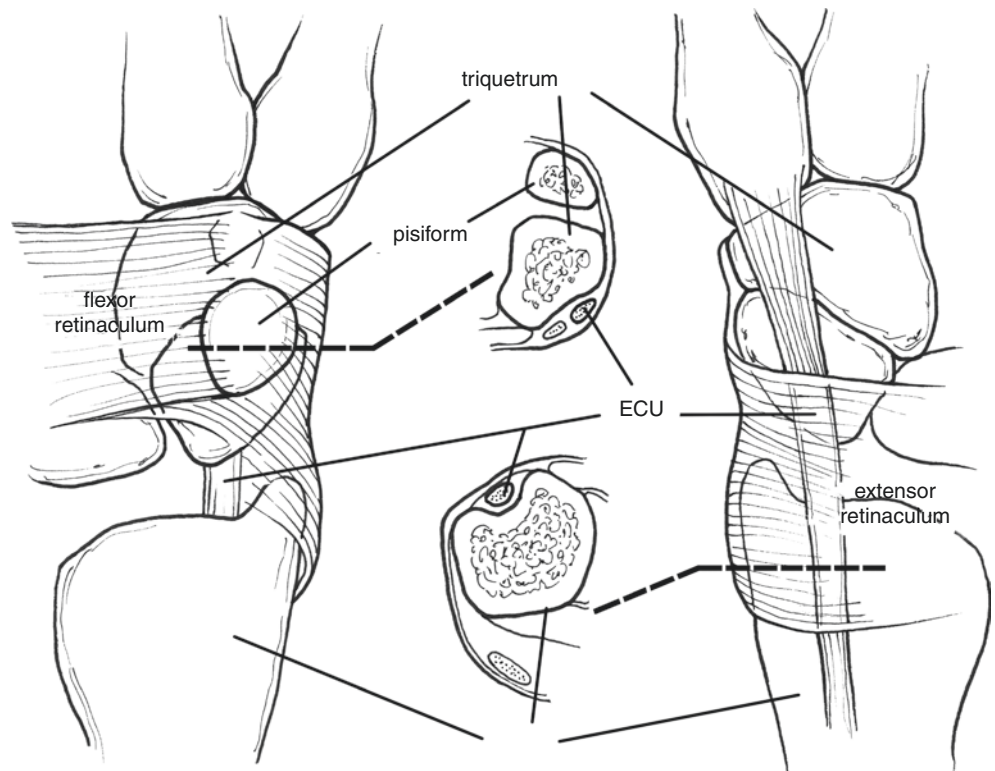
**Fig. 23.24** Incision to distal ulnar styloid. This incision is generally shorter, utilized in this dissection for demonstration purposes



**Fig. 23.25** Ulnar nerve, dorsal sensory branches

The sixth compartment must be respected, in that there are two retinacula: The primary retinaculum comes around the ulna and inserts into the pisiform; the second restrains the

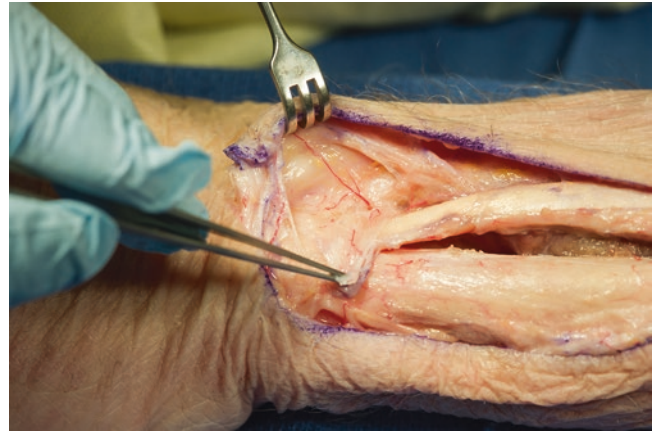
extensor carpi ulnaris (ECU) (Figs. 23.26, 23.27, 23.28, 23.29, 23.30, and 23.31).



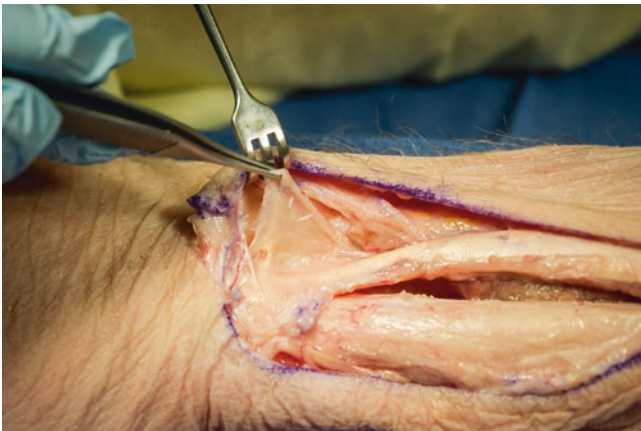
**Fig. 23.26** Diagram of primary and deep retinacula over the extensor carpi ulnaris (ECU)



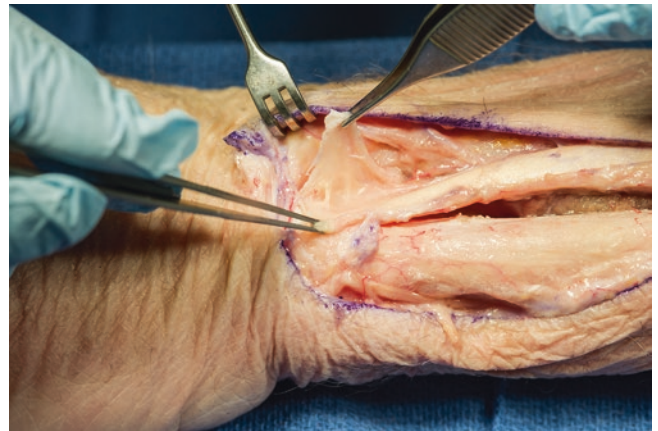
**Fig. 23.27** Retinaculum over sixth-compartment ECU



**Fig. 23.28** Retinacular flap radially based

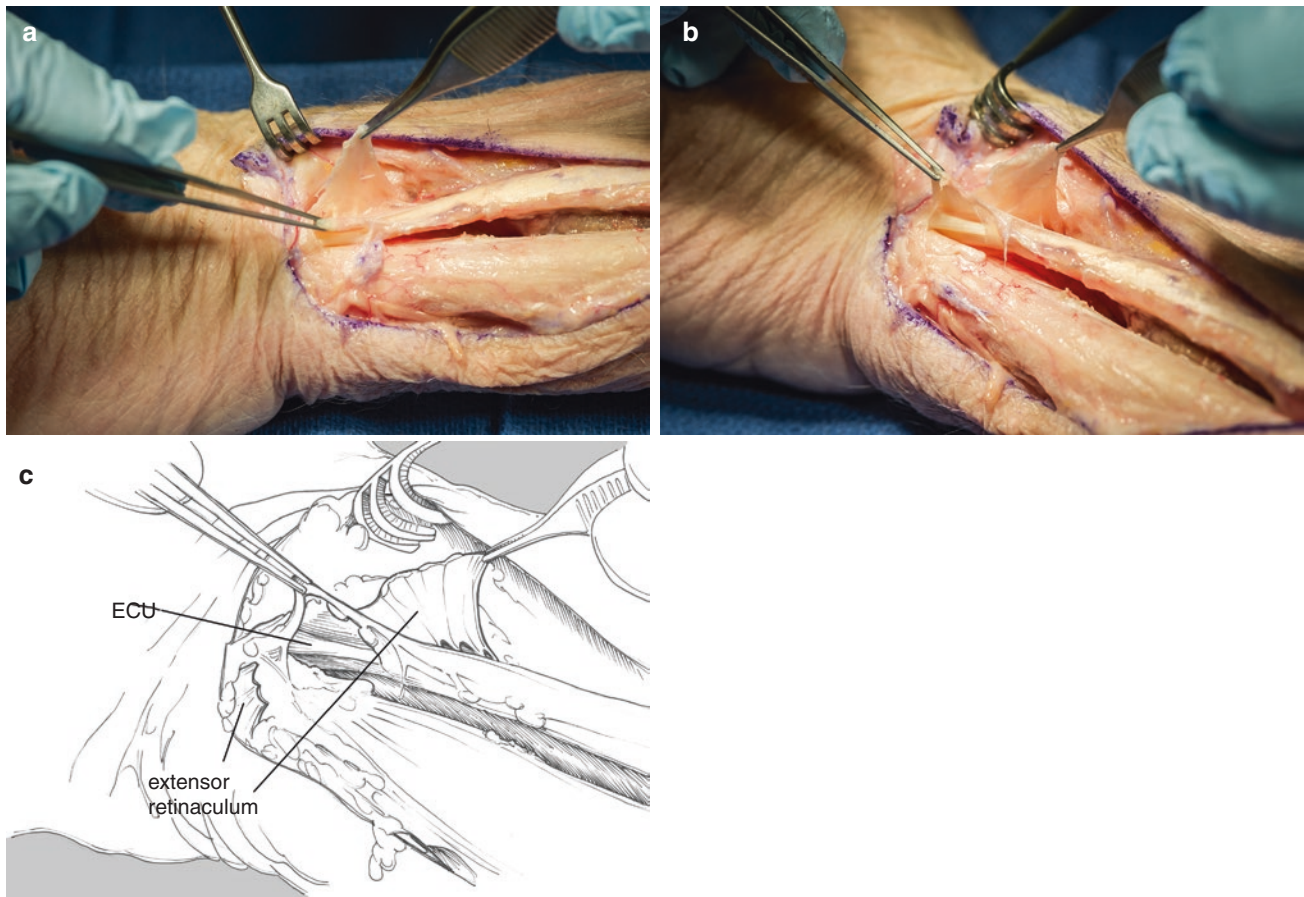


**Fig. 23.29** Elevated retinacular flap



**Fig. 23.30** Incision of deep retinaculum over ECU; see groove in ulnar head



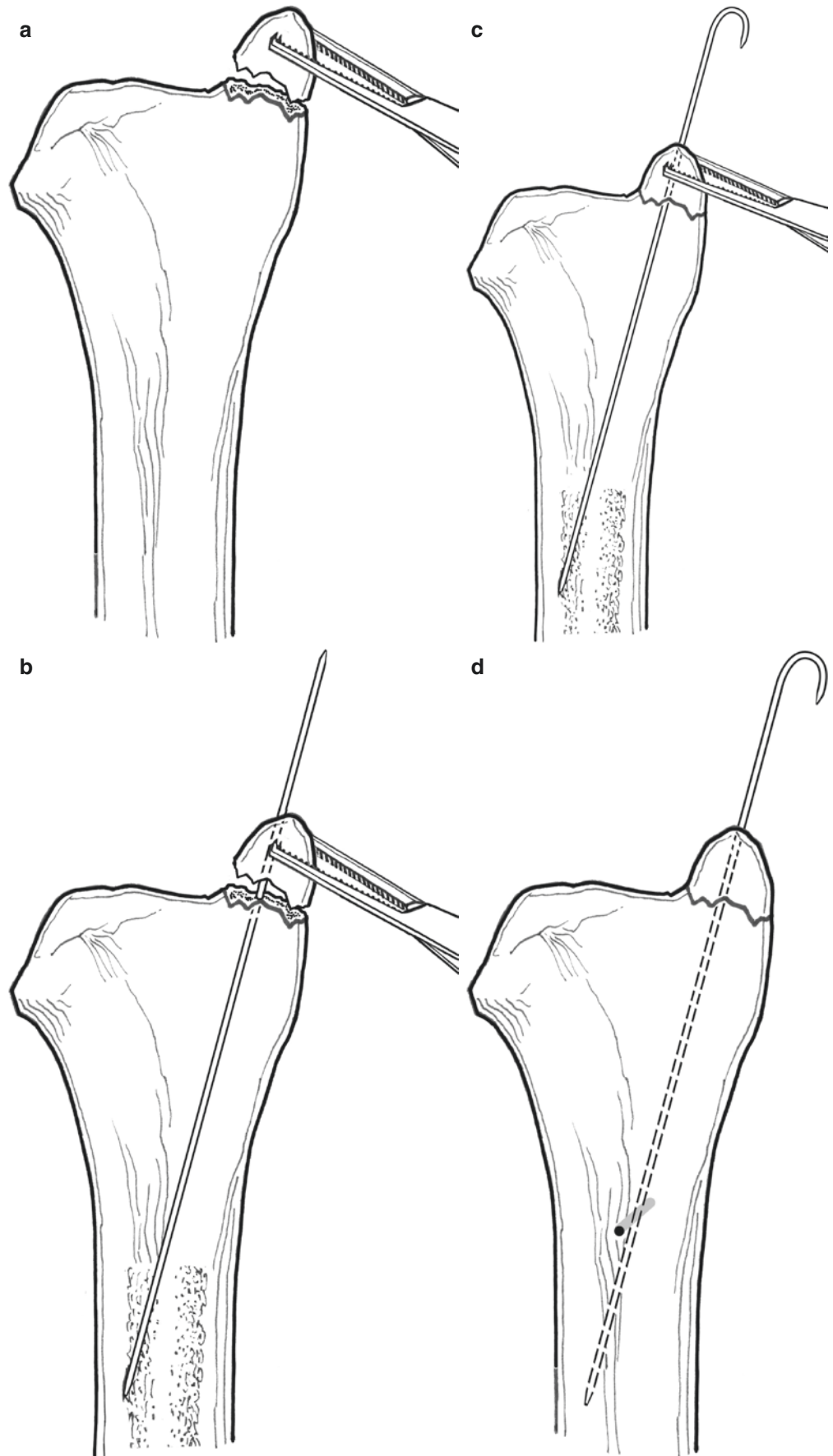


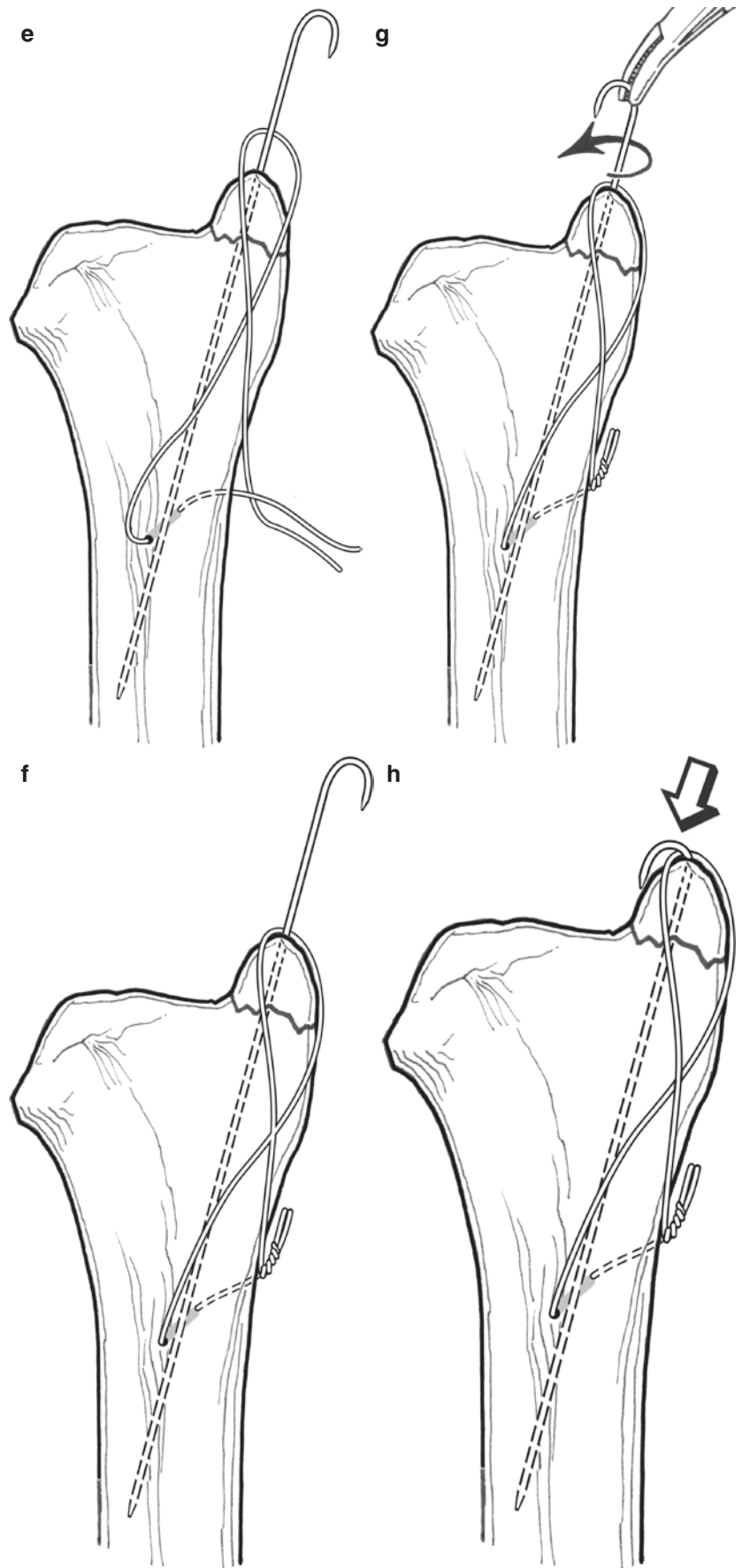
**Fig. 23.31** (a, b) Reflected deep retinacular flap. (c) Diagram of retinacula

I use a curved Kocher to hold the ulnar styloid. I use a 0.045-inch Kirschner wire (K-wire) from the tip of the ulnar styloid in an effort to go down the canal (Fig. 23.32a–c). A transverse 1.5-mm hole is drilled for the 24-gauge interosseous wire, which is then looped around the 0.045-inch K-wire. I use a single twist with the 24-gauge interosseous wire, because a double twist tends to weaken the overall construct by approximately 15% [14]. The 0.045-inch K-wire is bent, cut in an oblique fashion on the bias,

and then tamped into place to hold the 24-gauge interosseous wire. It is important to twist the interosseous wire first, before turning the K-wire, as the 24-gauge interosseous wire tends to break until one gets the feel of the tension on the wire; you will want to be able to place another wire prior to turning the K-wire and seating it into place (Figs. 23.32, 23.33, 23.34, 23.35, 23.36, 23.37, 23.38, 23.39, and 23.40).

**Fig. 23.32** (a–h) Sequence of ulnar styloid fixation



**Fig. 23.32** (continued)





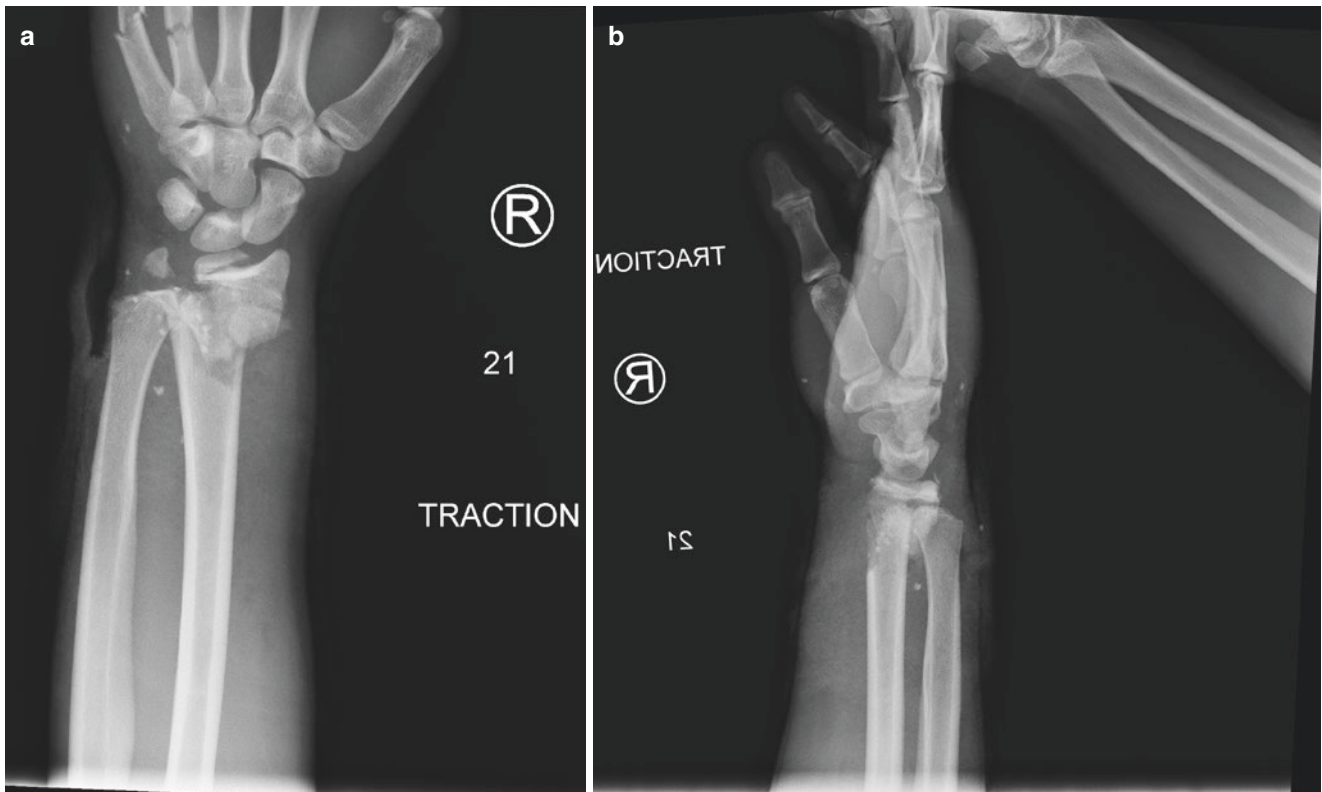
**Fig. 23.33** (a–c) Injury radiographs of left forearm Galeazzi fracture with ulnar styloid fracture. (d–f) Radiographs following ORIF with successful longitudinal Kirschner wire (K-wire) down ulna



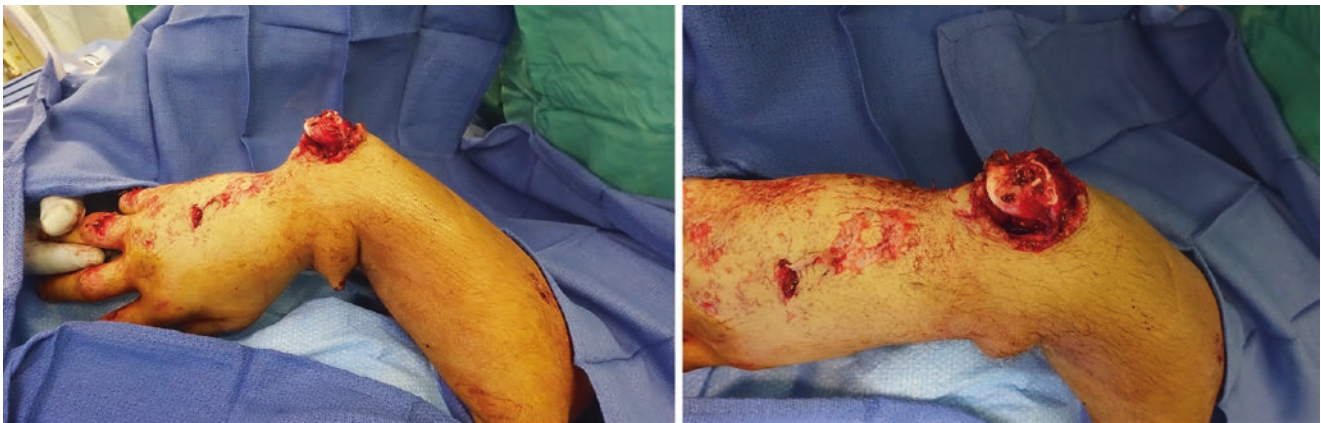
**Fig. 23.34** (a–c) Injury radiographs of left wrist Galeazzi fracture with ulnar styloid fracture. (d) and (e) Radiographs following fixation with K-wire, not intramedullary

**Fig. 23.34** (continued)**Fig. 23.35** (a, b) Radiographs of right wrist in splint. No films were obtained with the distal ulna protruding through soft tissue injury ulnarly

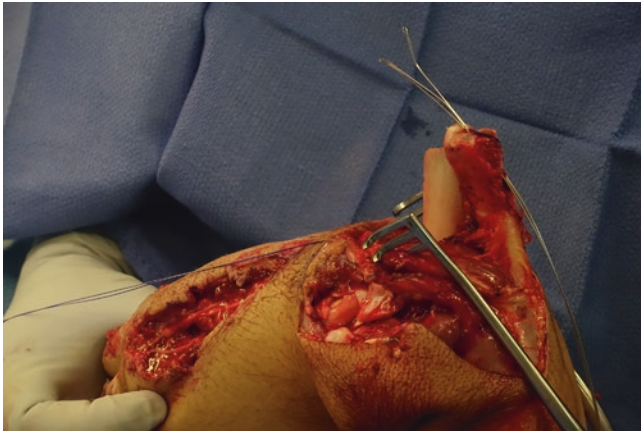




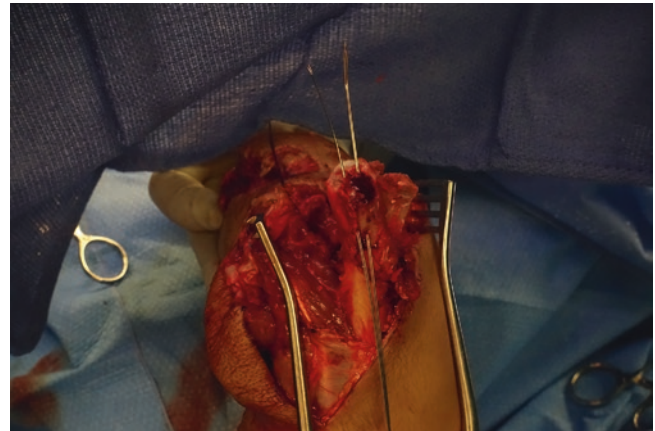
**Fig. 23.36** (a, b) Traction radiographs of reduced distal ulna with associated distal radius fracture



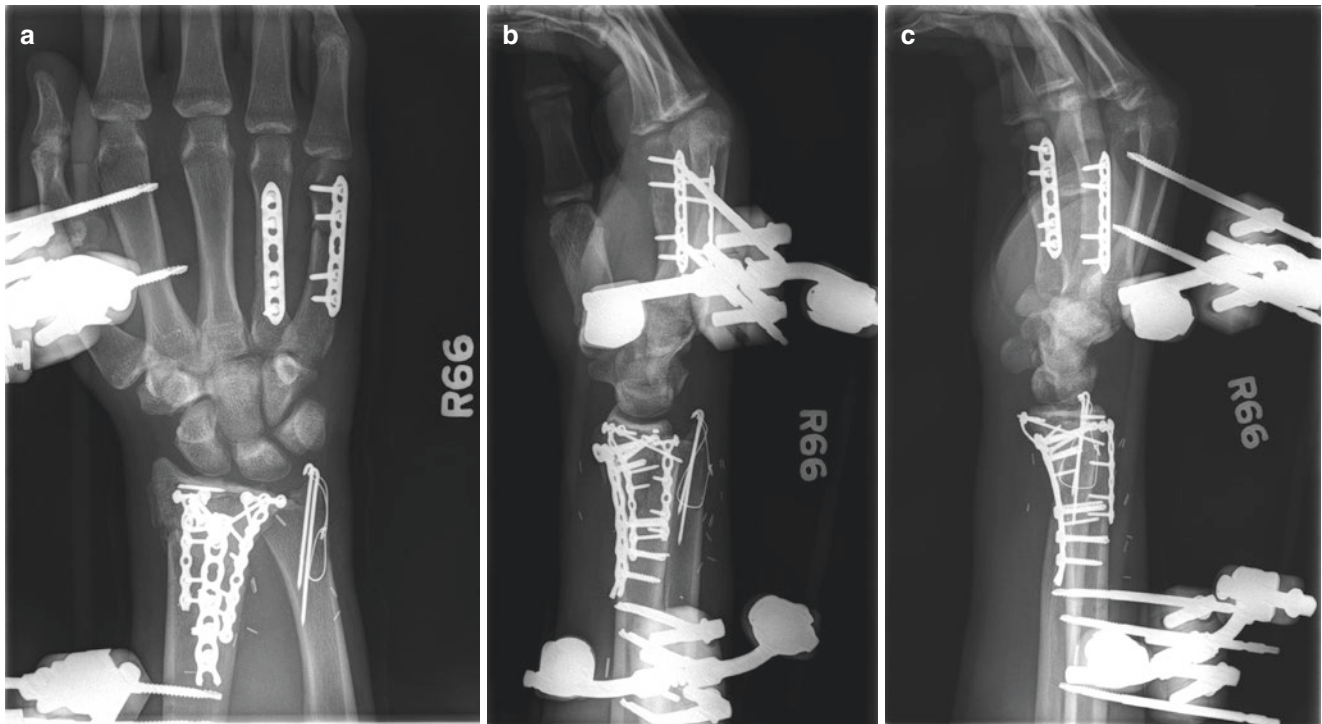
**Fig. 23.37** Right distal ulna protruding through ulnar laceration



**Fig. 23.38** 2-0 PDS® suture in the triangular fibrocartilage complex (TFCC) to be passed through 24-gauge wire placed through drill holes in the fovea. Sutures and hole drilling are performed prior to reduction to facilitate repair preparation



**Fig. 23.39** Lateral view of associated ulnar styloid fracture defect. Styloid fixation is to be performed along with TFCC repair



**Fig. 23.40** (a–c) Radiographs following ORIF of the ulnar styloid with the interosseous wire technique

## 23.5 Patient Rehabilitation

My postoperative immobilization is near-full supination using a sugar-tong splint. On the first postoperative visit, or if the patient is hospitalized for 2 or 3 days, he or she goes into a Munster brace in supination, generally in the range of 45–60°. The patient is allowed full elbow flexion and extension, and may use the hand for activities of daily living with rotation through the shoulder to attain a pronated position, but not at the forearm. At 2 weeks, a range of motion program from full supination to neutral is performed. At 4 weeks, the patient is allowed unrestricted activities, including strengthening, and weight-bearing as tolerated. Through years of using this protocol, only one DRUJ has required ligamentous reconstruction; this occurred decades ago in a patient who was maintained in a pronated position because of multiple medical conditions.

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### 24.1 Assessing the Distal Radius Fracture

The genesis of my approach to the distal radius harkens back a number of decades, to a time when the groundwork for treating the distal radius fracture had not been laid out. The distal radius seemed to be somewhat of a bastard stepchild and there was little interest in its treatment, particularly for intra-articular fractures, so I could begin developing my own philosophies. I began the process with the assumption that the amount of step-off that the joint could tolerate was, in fact, equal to the articular cartilage thickness. The next step involved the importance of defining the stability of the fracture and the ability to maintain a reduction once obtained. Out of that thought process came the concept of using the initial radiograph to assess stability, and a traction film for reducibility. As demonstrated by Cooney *et al.* [1, 2], when a distal radius has a dorsal tilt greater than 20–25°, the

likelihood of successful treatment is decreased because of inherent instability due to the dorsal comminution. The biomechanical correlate has been evaluated in a cadaver model by removing wedges of the distal radius to determine defects and dorsal angulations [3].

The traction radiograph facilitates the determination of the reducibility potential, particularly for an intra-articular fracture [4]. The traction view also provides information relative to approach, because intra-articular step-off is addressed dorsally unless there are large fragments in young bone that allow extra-articular fragment reduction to actuate intra-articular alignment. In comminuted fractures, the traction view may show angulation of the anterior and dorsal fragment in a “V sign,” which would necessitate an anterior approach for fragment reduction followed by a dorsal approach (Figs. 24.1, 24.2, 24.3, 24.4, and 24.5), though the V sign is not an exclusive indication for the anterior approach.

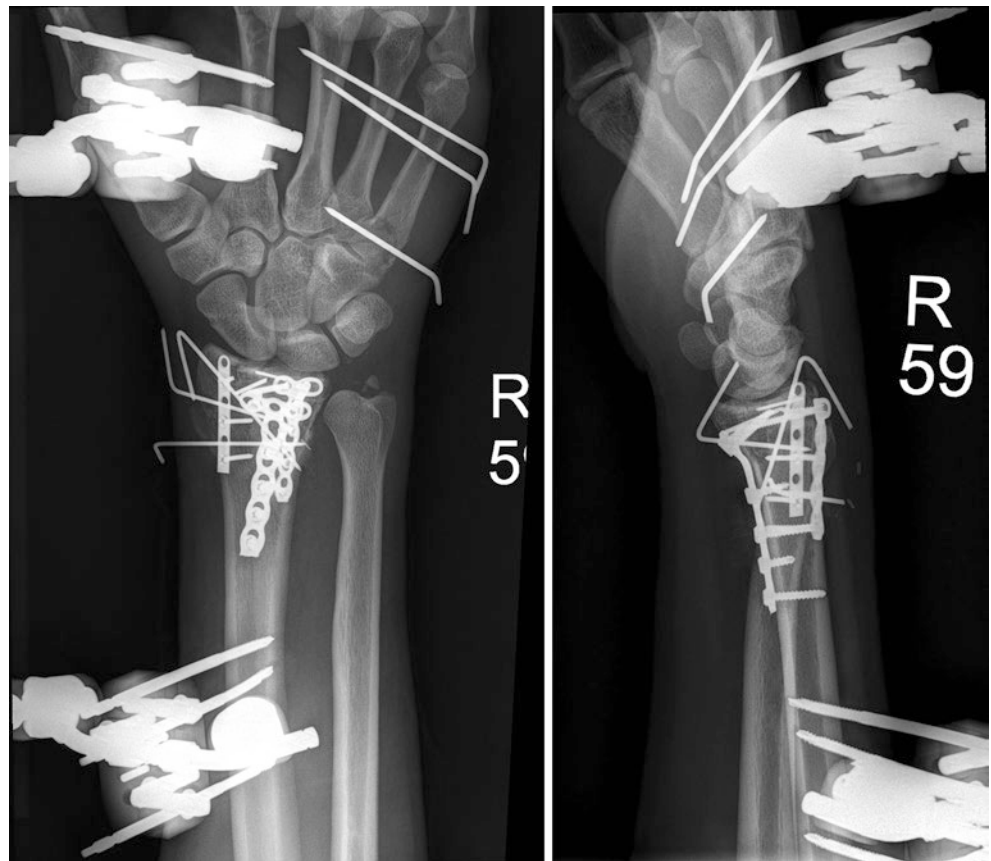


**Fig. 24.1** Injury radiographs of right distal radius fracture

**Fig. 24.2** Traction radiographs with V sign indicating the need for direct joint visualization and anterior posterior approach. Anterior approach performed first, prior to “stacking” on articular fragments dorsally



**Fig. 24.3** Intraoperative lateral radiograph displaying multiple provisional Kirschner wires (K-wires) during fixation

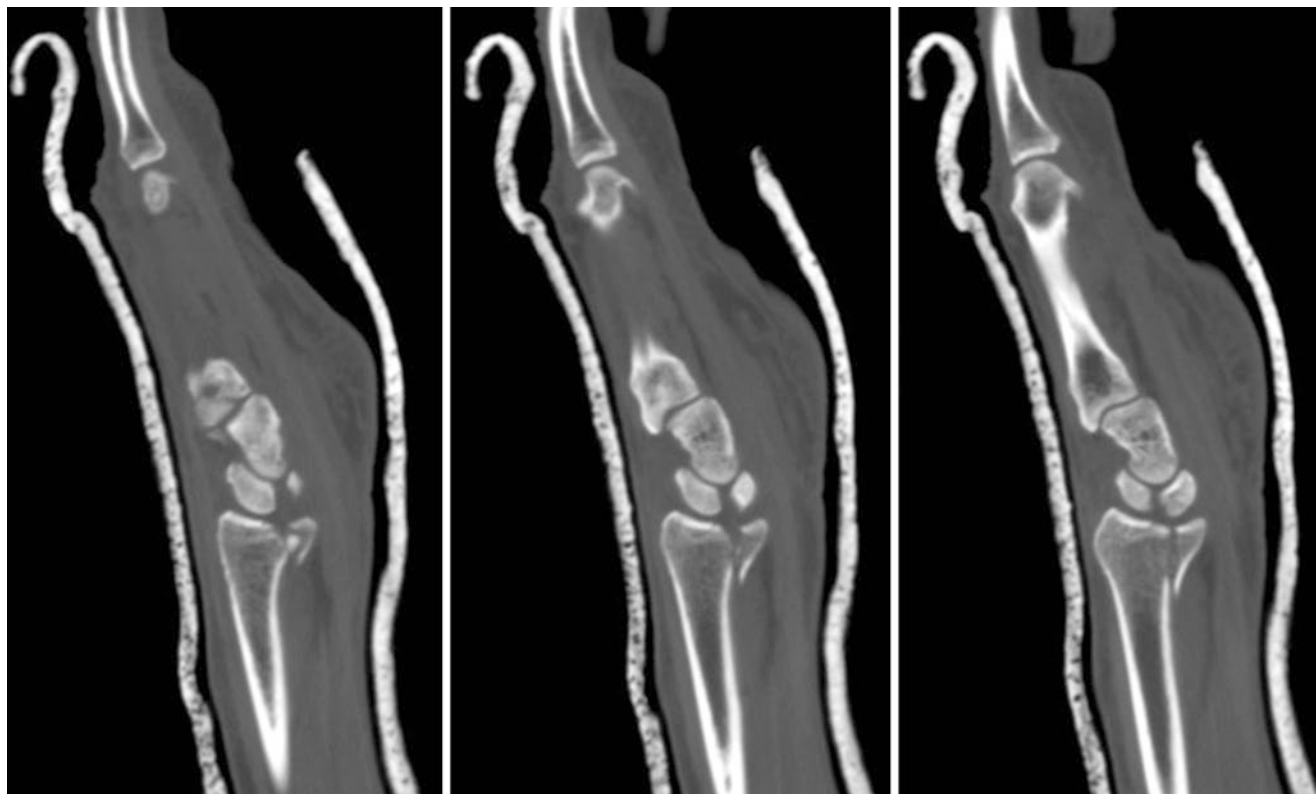
**Fig. 24.4** Final fixation**Fig. 24.5** Final radiographs



CT scans are not used unless there is a question of the need for surgery or of the approach (palmar or dorsal) to be applied. Normally, this information is available from the plain or traction radiographs (Figs. 24.6, 24.7, and 24.8).



**Fig. 24.6** Injury radiographs demonstrating palmar ulnar corner lunate facet fracture with potential for nonoperative treatment



**Fig. 24.7** CT scan revealing degree of displacement and potential for shearing and further displacement

**Fig. 24.8** Radiographs following open reduction and internal fixation (ORIF) of palmar ulnar corner fragment



## 24.2 How Important Is Articular Alignment?

Once you have obtained acceptable intra-articular alignment in the traction radiographs, the next step is essentially emotion-based. I believe that the outcomes are effectively equal whether the fracture is treated with external fixation, percutaneous fixation, or open reduction internal fixation (ORIF). This has been demonstrated now with a number of projects that address primarily extra-articular fractures, but also minimally displaced intra-articular fractures (Table 24.1) [5–11].

The need for attempted re-reduction has been questioned, particularly in patients who are over the age of 65 [12].

The paper by Knirk and Jupiter [13] was one of the first that demonstrated the importance of articular alignment. Though it is frequently stated that a step-off of 2 mm or more should not be tolerated, this paper reported an incidence of arthritic development of 11% at a step-off of 0–1 mm, compared with 87% at 1–2 mm and 100% at greater than 2 mm. These numbers suggest that maybe 1 mm should be the critical limit, but radiographic arthritis did not necessarily correlate with clinical limitations.

The premise that I have invoked—that intra-articular step-off or separation should be less than 1 mm—is also

supported in three reports [14–16]. Less than 1 millimeter is commensurate with articular cartilage thickness [17]. Bradway *et al.* supported 2 mm as the critical step-off [18]. Wagner *et al.* [15] noted greater force alteration with step-off of only 1 mm in the scaphoid fossa compared with the lunate fossa step-off. Baratz *et al.* [19] also determined in a cadaver study that 1 mm of intra-articular step-off resulted in a significant increase in stress and overloading, with a notable increase in stress towards the osteotomy line. The model, however, created the osteotomy in the interfossal ridge, which is normally a non-force-transmitting area, as opposed to the central scaphoid or lunate fossa areas, where the major forces are transmitted. Nevertheless, the impact of even a 1-mm step-off was demonstrated.

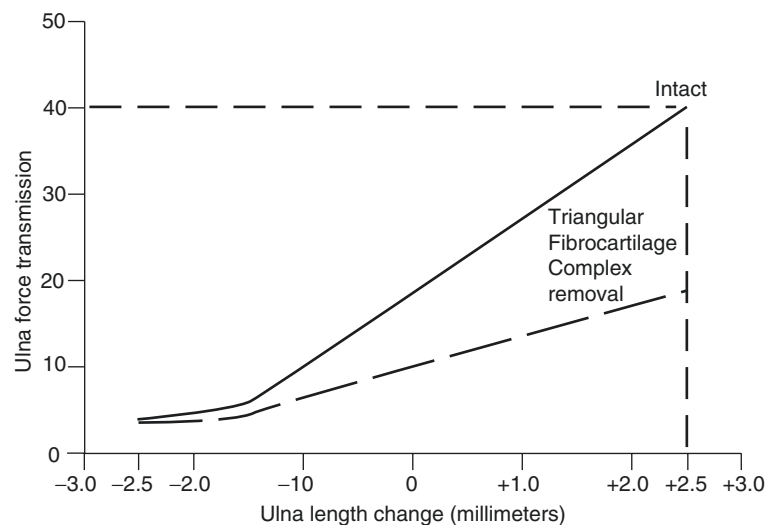
More than 3 mm of shortening was shown by Aro and Koivunen [20] to be problematic. Functional disability in patients was evaluated relative to radial shortening: 4% unsatisfactory with anatomic alignment; 25% unsatisfactory with shortening of 3–5 mm; and 31% unsatisfactory with shortening greater than 5 mm.

Mechanical studies have demonstrated that force transmission is significantly altered at 2.5 mm of ulnar lengthening: distal ulna force transmission was increased from 18 to 42% [21] (Fig. 24.9).

**Table 24.1** Studies assessing treatment outcomes for distal radius fractures

Author	Year	Type of Study	Treatments	Results
Wright <i>et al.</i> [5]	2005	Retrospective, Unstable distal radius fx	ORIF (anterior with fixed-angle implant), 21 fx vs. ExFix, 11 fx	ORIF: Better intra-articular step-off, palmar tilt, radial length Functional outcome equal
Egol <i>et al.</i> [6]	2008	Prospective, Unstable distal radius fx	Bridging ExFix with K-wires, 38 pts. (more pts. with type C fx) vs. Anterior locked plate, 39 pts	Functional outcomes similar at 1 year
Arora <i>et al.</i> [7]	2011	Prospective, Unstable distal radius fx, pts. age $\geq 65$ years	Nonoperative, 37 pts. vs. Anterior locking plate, 36 pts	ROM, pain, functional scores no different at 1 year Operative group: better grip
Grewal <i>et al.</i> [8]	2011	Prospective, Failed closed reduction	ORIF, 27 pts. vs. ExFix, 26 pts	Patient-related wrist evaluation (PRWE) score initially lower with ORIF, but equalized at 1 year Higher initial PRWE in ExFix group may indicate more severe injury
Wei <i>et al.</i> [9]	2012	Meta-analysis: 12 studies	ORIF (520 pts) vs. ExFix (491 pts)	ORIF: Better DASH score, forearm supination, palmar tilt ExFix: Better grip, wrist flexion
Esposito <i>et al.</i> [10]	2013	Meta-analysis: 10 studies	ORIF plate vs. ExFix	ORIF: Lower DASH score, better radial length, decreased infection
Xie <i>et al.</i> [11]	2013	Meta-analysis: 10 studies	ORIF vs. ExFix	ORIF: Better DASH score at 3 and 6 months, but no difference at 12 months ORIF: Better palmar tilt, radial inclination; fewer minor complications; pts. recovered sooner

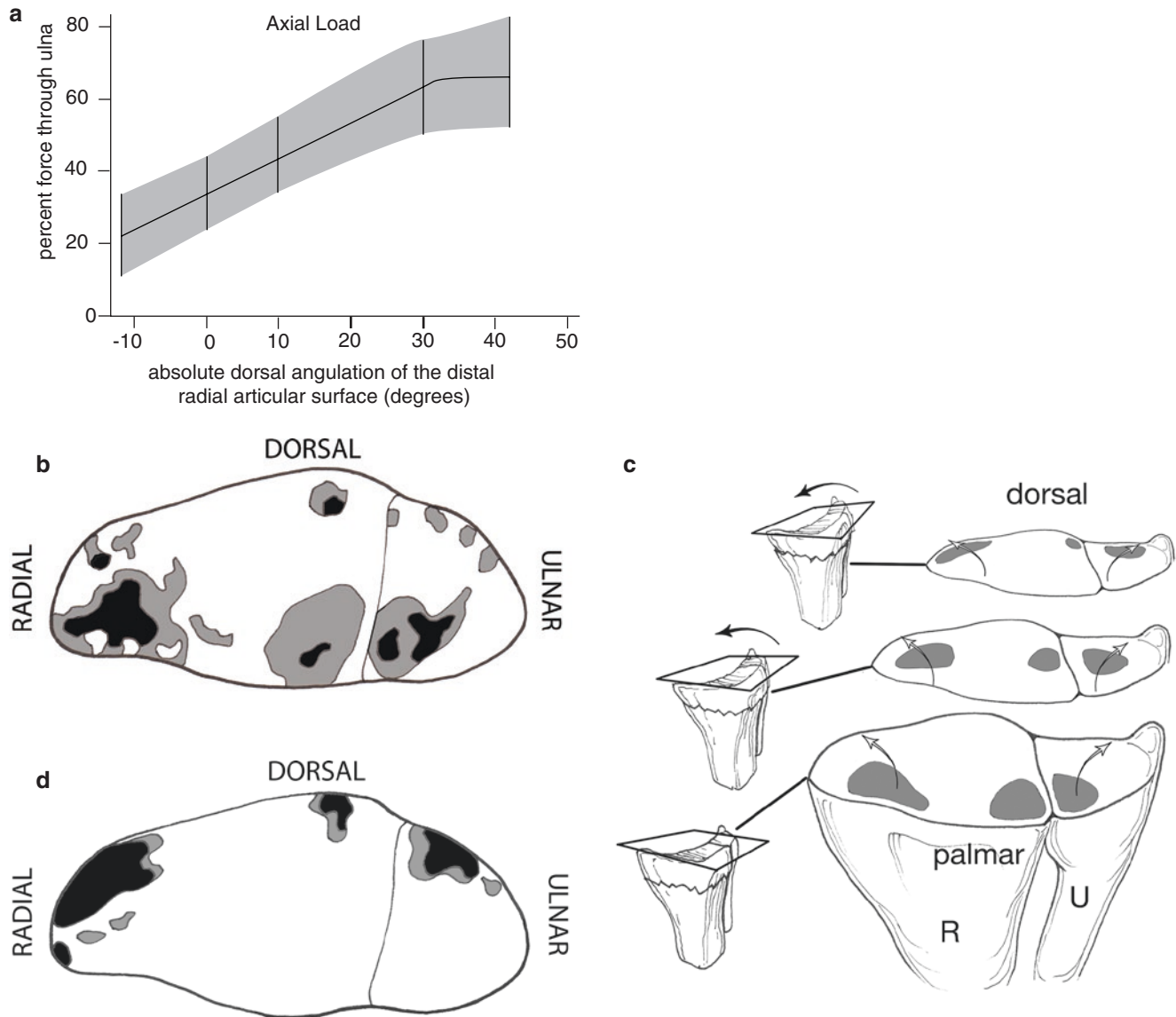
DASH disability of the arm, shoulder, and hand, *ExFix* external fixation, *ORIF* open reduction internal fixation, *PRWE* patient-rated wrist evaluation, *ROM* range of motion

**Fig. 24.9** Result of ulna shortening and lengthening on force transmission across the distal ulna



With restoration of the palmar tilt, the classically cited die punch (dorsoulnar) fragment is not as important, because the force transmission as demonstrated in the above reports is palmar and is centered in the lunate and scaphoid fossas [22]. With increasing dorsal tilt, the forces migrate dorsally, radially, and ulnarly, and then the contact is shifted towards the die punch fragment. Finally, a dorsal tilt of less than  $10^\circ$  in a younger

individual and less than  $20^\circ$  in an older person (representing a  $20^\circ$  shift from normal in the younger group and  $30^\circ$  in the older group) is the “acceptable” limit. This harkens back to forced transmission studies that demonstrated shifts in force contact areas. Distal ulnar forces that initially bore 21% of the load were increased to 40% with a  $20^\circ$  change (to  $10^\circ$  dorsal tilt) and to 50% with a  $30^\circ$  change (to  $20^\circ$  of dorsal tilt) [22] (Fig. 24.10).



**Fig. 24.10** (a) Effect of dorsal angulation and force transmission through the distal ulna. (b) Intact distal radius force concentration areas; note the palmar, central scaphoid, and lunate fossas. (c)

Diagrammatic representation of dorsal tilt and shifting of the force transmission with increasing tilt of the radius. (d) Concentrated force transmission contact areas with  $20^\circ$  of dorsal tilt ( $30^\circ$  change)

Two issues arise: One is the ability to ascertain the degree of step-off [23]. The second is whether residual incongruity with the development of arthritis necessarily correlates with a decreased functional outcome [22, 24]. The ability to evaluate the intra-articular step-off has been noted by a number of

individuals who looked at plain radiographs and fluoroscopic and CT scans, with the CT scan being superior [25]. Noting that an intra-articular step-off of 1 mm is difficult to ascertain and is not necessarily correlated with arthritic development, more specificity is needed as to the location of the step-off.

## 24.3 Determining the Treatment Plan

### 24.3.1 Nonoperative Treatment

When determining a treatment plan, isolated extra-articular fractures and intra-articular fractures with acceptable alignment and stability following reduction are still treated

nonoperatively. Reduction in supination, traction, mid-carpal extension, and distal fragment anterior translation is followed by use of a sugar-tong splint for 7–10 days. A short arm cast is then applied for 4–5 weeks, with occasionally a cast change within this time frame if needed because of decreased swelling (Figs. 24.11, 24.12, 24.13, 24.14, 24.15, 24.16, 24.17, 24.18, 24.19, 24.20, 24.21, and 24.22).



**Fig. 24.11** Injury radiograph of extra-articular right distal radius fracture treated nonoperatively

**Fig. 24.12** Sugar-tong splint**Fig. 24.13** Short arm cast



**Fig. 24.14** Discharge radiographs



**Fig. 24.15** Injury radiographs of left distal radius fracture



**Fig. 24.16** Traction radiographs



**Fig. 24.17** Radiographs of patient in sugar-tong splint, then transitioned to short arm cast

**Fig. 24.18** Radiographs at time of discharge; right wrist shown for ulnar variance comparison



**Fig. 24.19** Injury radiographs demonstrating intra-articular right distal radius fracture

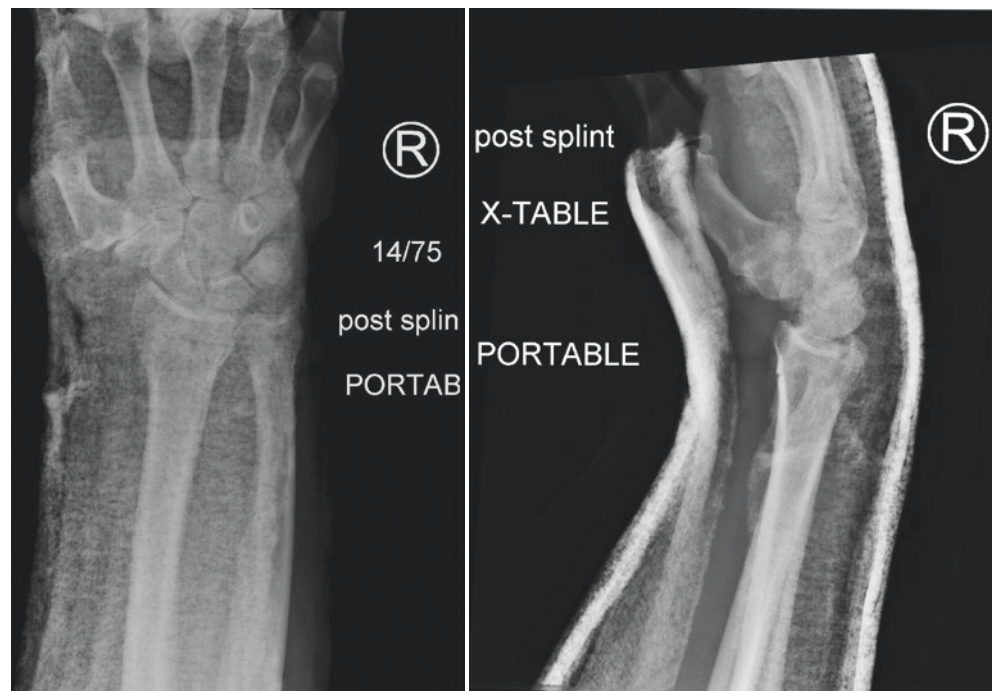




**Fig. 24.20** Traction radiograph



**Fig. 24.21** Splinting radiographs; the patient elected nonoperative treatment



**Fig. 24.22** Final radiographs revealing increased dorsal tilt and settling increased from the initial alignment (a commonly seen issue)



During the follow-up period, some issues may arise. I've had a number of fractures treated closed that have gone on to a dorsal tilt greater than what was seen on the initial injury radiographs, despite attention to splinting and casting with proper molds. Because the initial phase of fracture healing is resorption or an osteoclastic process, the fracture actually becomes more unstable and can collapse, as seen in Fig. 24.22. This brings me to my second point: You

should compare the follow-up radiographs to the initial reduction films in order to get a true reflection of alignment changes. You can be lulled into a false sense of little change if you are just checking sequential radiographs. Proper radiographs are required and will take some interaction with the radiology staff, particularly to obtain the inclined shots (Figs. 24.23, 24.24, 24.25, 24.26, 24.27, 24.28, 24.29, and 24.30).



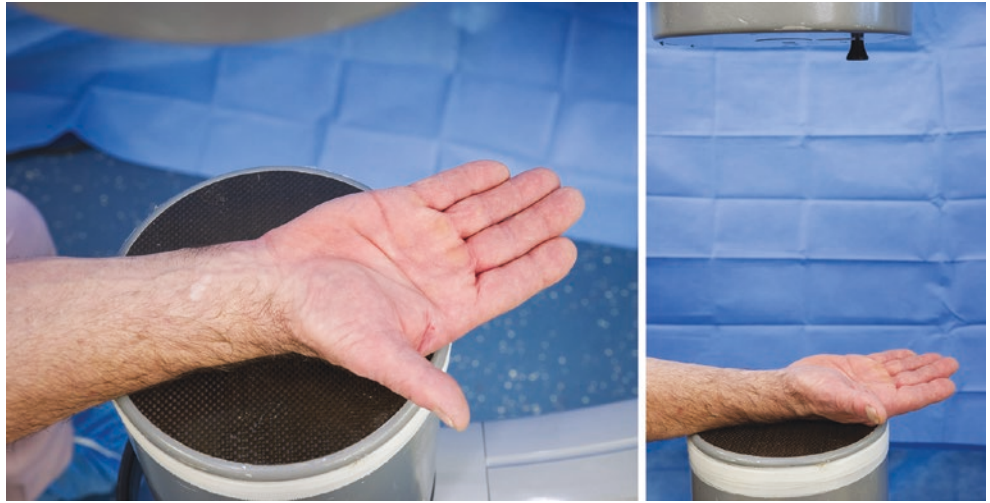
**Fig. 24.23** Posteroanterior (PA) radiographs of positioning of right wrist



**Fig. 24.24** PA radiograph



**Fig. 24.25** Anteroposterior (AP) radiograph of positioning of right wrist



**Fig. 24.26** AP radiograph of right wrist



**Fig. 24.27** Lateral radiograph positioning of right wrist without inclination, blocking joint visualization



**Fig. 24.28** Lateral radiographs, no inclination



**Fig. 24.30** Inclined lateral radiograph clearing joint



**Fig. 24.29** Inclined positioning for radiograph for better joint evaluation

### 24.3.2 Surgical Options: External Fixation

There are a number of potential surgical options with distal radius fracture. Three are noted here: external fixation, percutaneous fixation, and ORIF. These are not mutually exclusive, but will be separately addressed and occasionally intertwined. For the sake of completeness, I also should acknowledge spanning bridge plates, which I don't use [26, 27]. Also, I do not use arthroscopy to evaluate for intra-articular ligament injury or joint reduction, as these techniques do not alter the treatment plan with the sequence of interventions that I use [28–32]. The prepping and draping sequence for all the options is demonstrated in Chap. 21.

External fixation is used very commonly either because of poor bone quality or extreme comminution of an intra-articular distal radius fracture, such that a single device would not afford adequate fixation. External fixation insertion and positioning is more a dorsal palmar orientation, rather than radial ulnar [33]. I place the pins in a dorsal palmar fashion, as this is more in the direction that the fracture occurs. This position neutralizes the compressive forces and moves the external fixator out of the radial plane, which can have a negative impact on the patient's subsequent function.

The half-pins, which are 3 mm in size, are placed about 7 cm proximal to the radial styloid if the external fixation is the primary means of fixation, or with associated percutaneous K-wire fixation. The half-pins are placed more proximally, depending on the need of internal fixation of the radius. The more proximal incision for the half pin insertion avoids incision overlap, creating a bipedicle flap consequent to the incision for the open reduction internal fixation of the distal radius fracture. The incision begins approximately 7 cm proximal to the radial styloid, and is about 4 cm in length, with a

radial orientation. Three separate dorsal incisions are outlined in a 1, 2, 4 distal-to-proximal fashion in the position equal to the half-pin slots in the pin clamp, going distal to proximal. The index metacarpal pins are placed in a 1, 3-spread using the Stryker® system. Under tourniquet control, the incisions are carried out. Careful subcutaneous resection is performed; be aware of the lateral antebrachio-cutaneous nerve and cephalic vein. Depending on the orientation, the nerve and vein can be retracted either anteriorly or posteriorly (Figs. 24.31, 24.32, 24.33, and 24.34).



**Fig. 24.31** Incisions outlined for half pin insertion in radius for external fixator



**Fig. 24.32** Skin edges reflected, exposing the cephalic vein (*black arrow*) and lateral antebrachio-cutaneous nerve (*white arrow*)





**Fig. 24.33** Deeper superficial branch of the radial nerve exiting 7–8 cm proximal to the radial styloid, between the brachioradialis and extensor carpi radialis longus



**Fig. 24.34** Wider exposure for demonstration purposes, not an extended external fixator approach. Hook lifting superficial branch of radial nerve

The next structure to identify is the brachioradialis, which is a triangular tendon with a flame-shaped muscle with the superficial branch of the radial nerve (SBRN) between the brachioradialis and extensor carpi radialis longus (ECRL) (Fig. 24.35). The interval for placing the half-pins is between

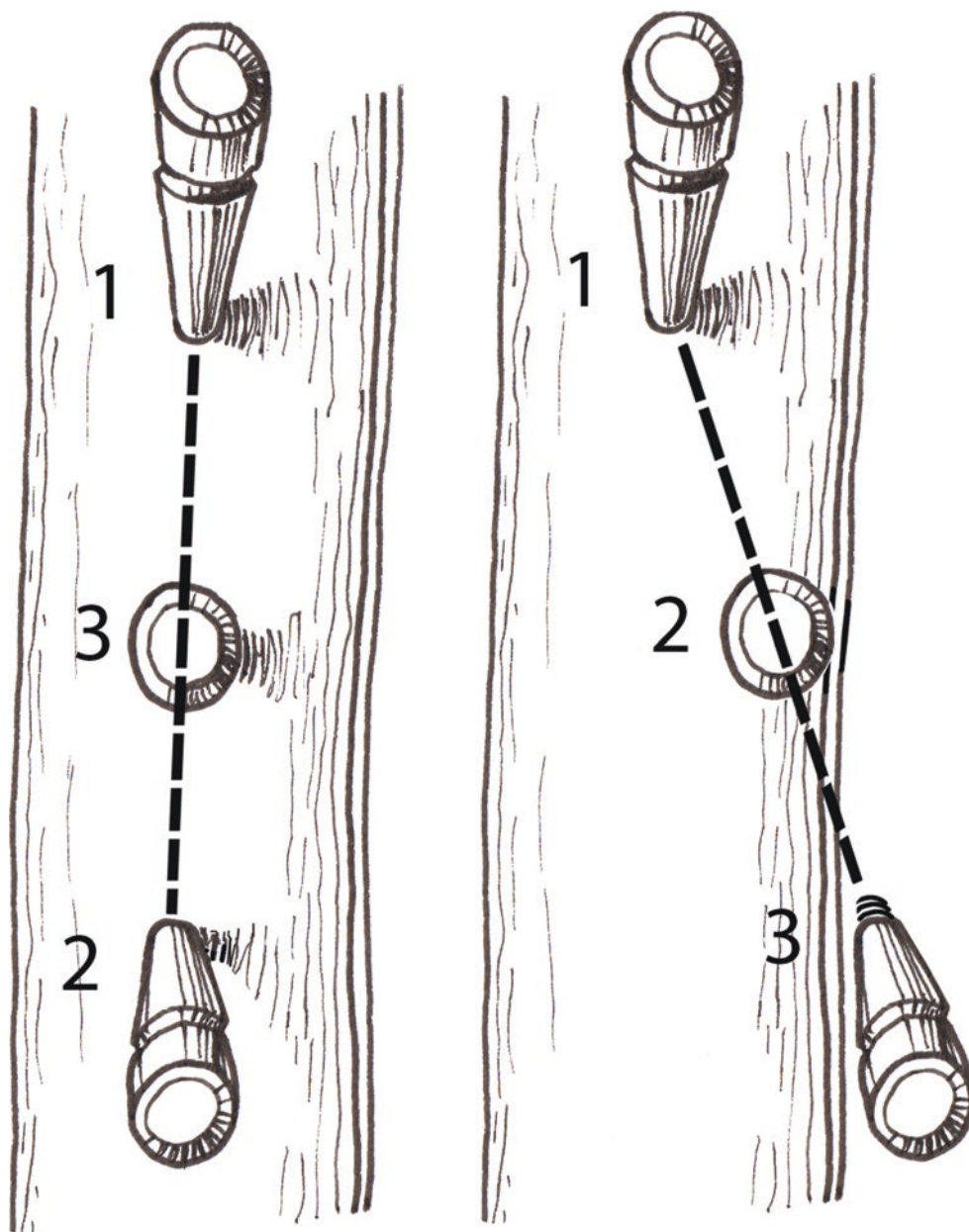
the ECRL and extensor carpi radialis brevis (ECRB), just proximal to the abductor pollicis longus. Through the approach incision, the pre-drilling is carried out in a 1, 4, 2 sequence, beginning distally followed by insertion of the 3-mm half-pins through the separate dorsal incisions.



**Fig. 24.35** Characteristic morphology of the brachioradialis with triangular tendon and flame-shaped muscle

The clamps are four-pin clamps. In general, when three half-pins are to be placed, I drill the outboard holes first to ensure that the third pin is in the bone (Fig. 24.36).

**Fig. 24.36** Half-pin insertion sequence to ensure that all pins are in the bone; an aberrant inboard half pin can force the subsequent pins to miss



I place a self-restraining retractor between the ECRL and ECRB and pre-drill with the retractor left in place; I then place the proximal and distal pins, so that I can ensure a

proper insertion interval (Figs. 24.37, 24.38, 24.39, 24.40, 24.41, 24.42, and 24.43).

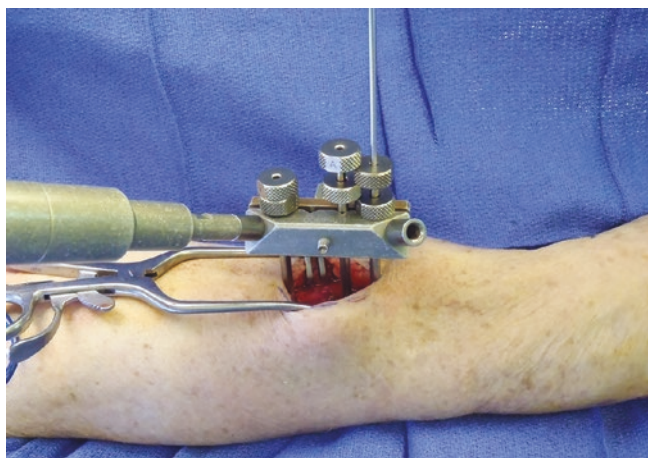
**Fig. 24.37** Injury radiographs of right distal radius fracture in a patient with bilateral distal radius fractures



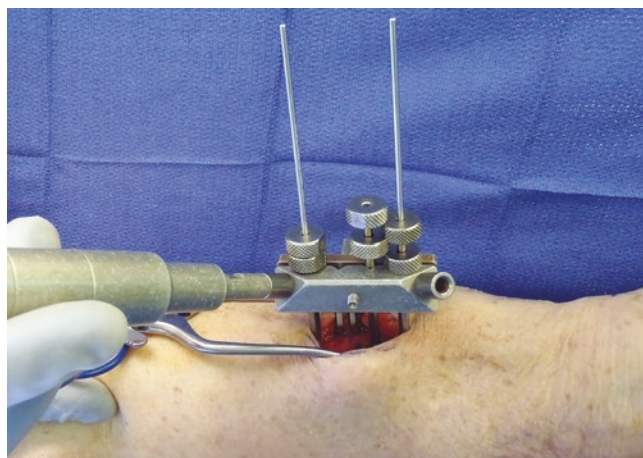
**Fig. 24.38** Traction radiographs



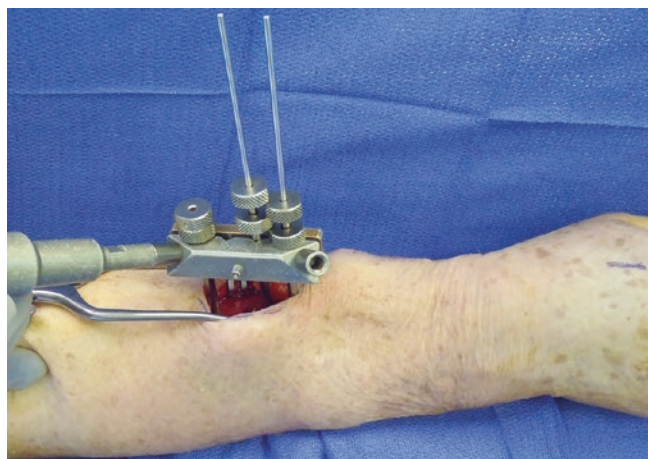




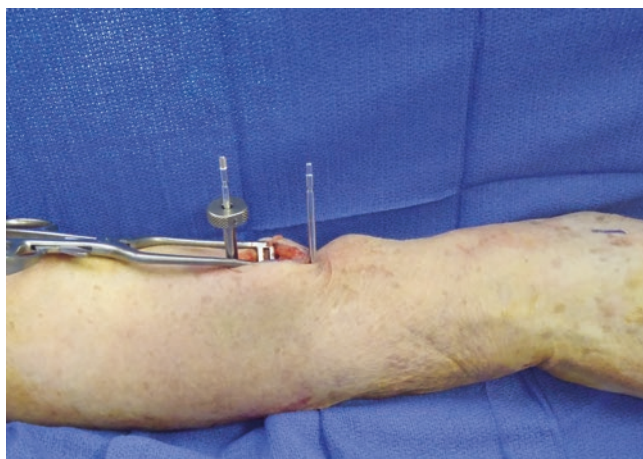
**Fig. 24.39** Jig in place between extensor carpi radialis longus and brevis on right forearm. A 2.2-mm distal drill bit was drilled and left in place



**Fig. 24.40** Proximal hole drilled, then drill bit removed

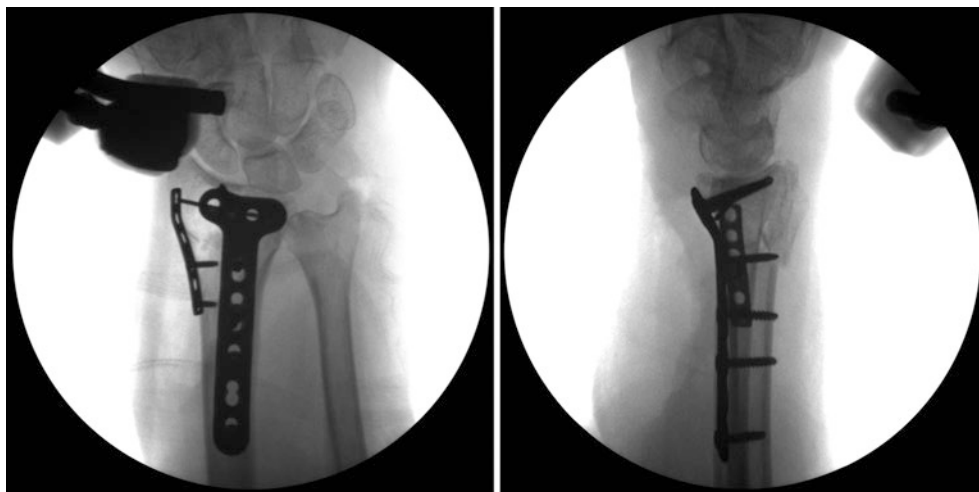


**Fig. 24.41** Center hole drilled



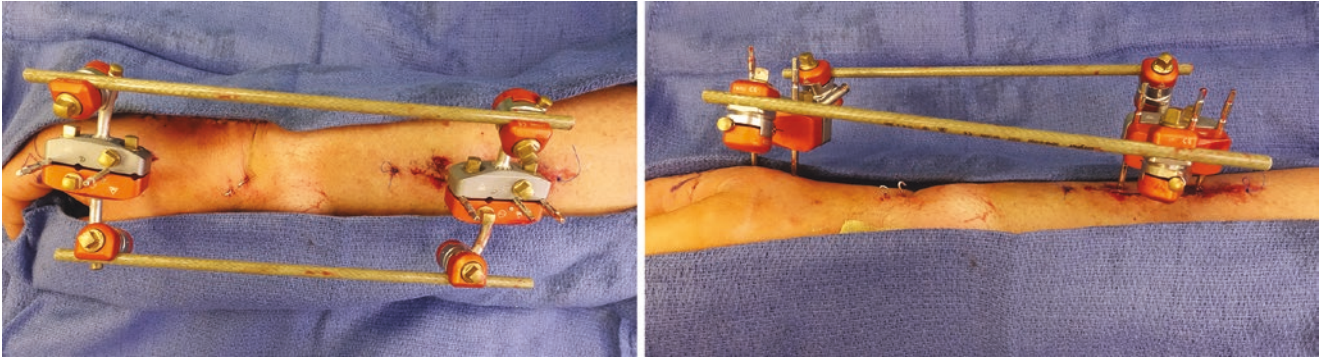
**Fig. 24.42** Half pins inserted through separate dorsal incision. Note that the self-retractor has not been removed, and distal incisions are outlined for metacarpal half-pins insertion after the third half pin has been placed in the forearm

**Fig. 24.43** Intraoperative radiographs following open reduction internal and external fixation, utilized because of concern over bone quality and potential screw cut-out



Separate incisions are then performed over the index metacarpal, with direct metacarpal visualization. The pins are placed at about a 60° angle, as there is generally a flat surface of the metacarpal. The first pin will be at the proximal meta-diaphyseal flare. I pre-drill for the first and insert the half-pin. Then, through the jig, I drill and place the second pin. Clamps

are applied with the nuts placed outboard, so that you will not need to cross over the patient to perform any adjustments (Figs. 24.44 and 24.45). Reduction is performed with longitudinal traction, supination, mid-carpal extension, and palmar translation of the distal fragment [34].



**Fig. 24.44** Constructed external fixator with MRI-compatible frame

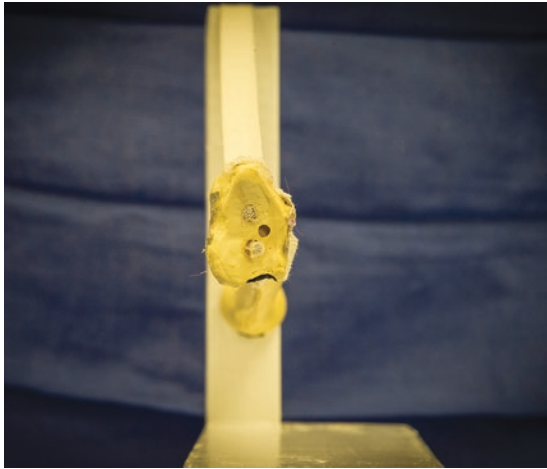


**Fig. 24.45** Alternate frame with non-MRI-compatible couplings, with a lip to limit popping off when tightened

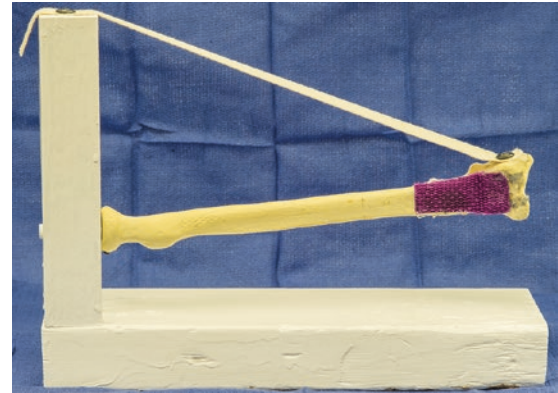


Sarmiento *et al.* [35] demonstrated that supination is the preferred position, as it helps the brachioradialis to exert a

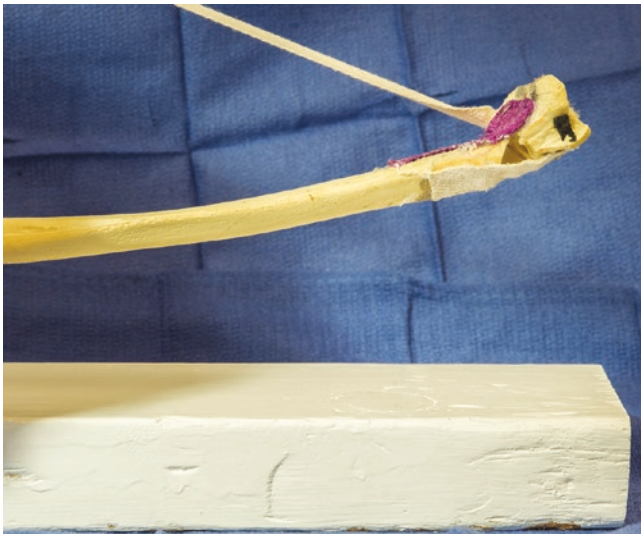
palmar reduction of the distal fragment (Figs. 24.46, 24.47, 24.48, and 24.49).



**Fig. 24.46** Model constructed to demonstrate the effect of the pull on the left distal radius by the brachioradialis



**Fig. 24.47** Purple strap represents the pronator quadratus. Neutral pronation and supination



**Fig. 24.48** Supination with palmar tilt and reduction actuated



**Fig. 24.49** Pronation with dorsal tilt of distal fragment and collapse into defect

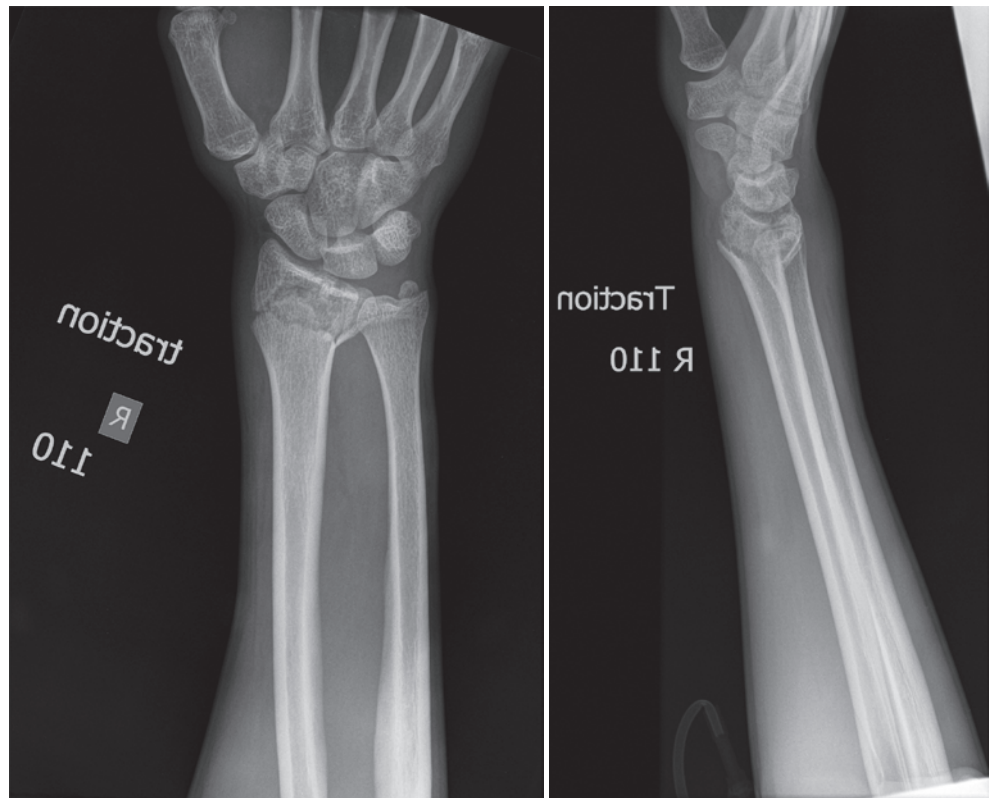


The supinated position has been supported by a number of reports and studies [36–38]. The frame is constructed and tightened (Figs. 24.50, 24.51, 24.52, 24.53, 24.54, 24.55, 24.56, 24.57, 24.58, 24.59, 24.60, and 24.61).

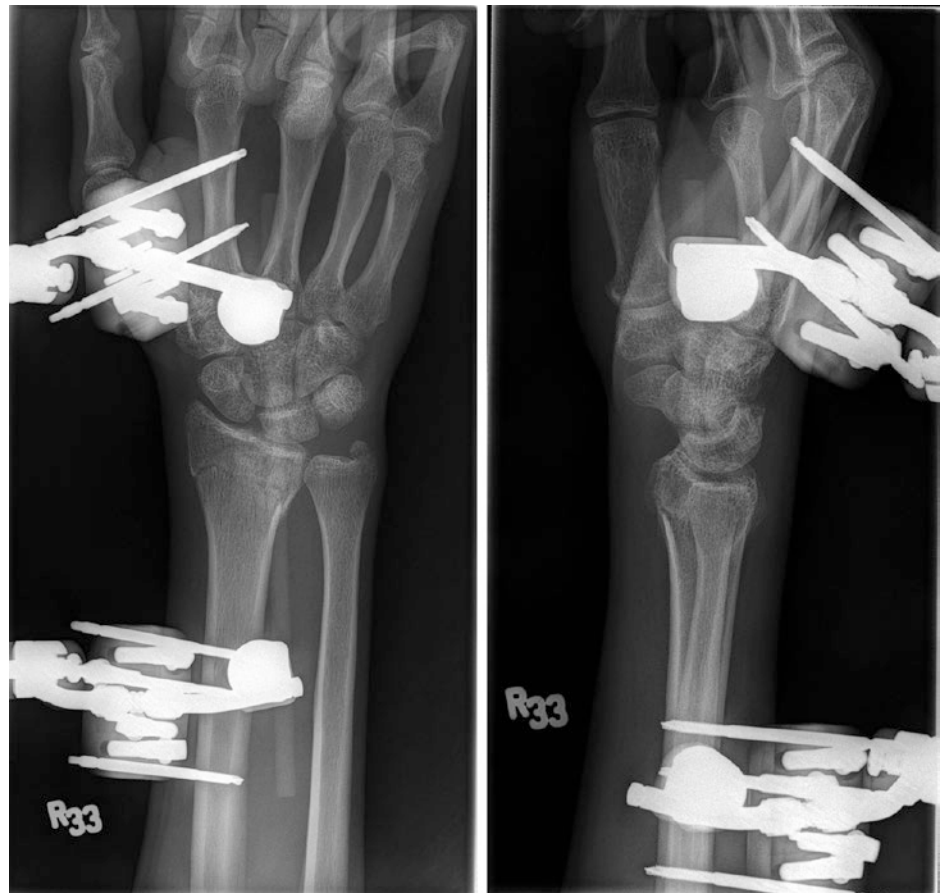


**Fig. 24.50** Injury radiographs of intra-articular right distal radius fracture

**Fig. 24.51** Traction radiograph demonstrates improvement of intra-articular alignment



**Fig. 24.52** Reduction and fixation radiographs utilizing external fixation. Reduction performed with traction, supination, anterior distal radius translation, and wrist extension



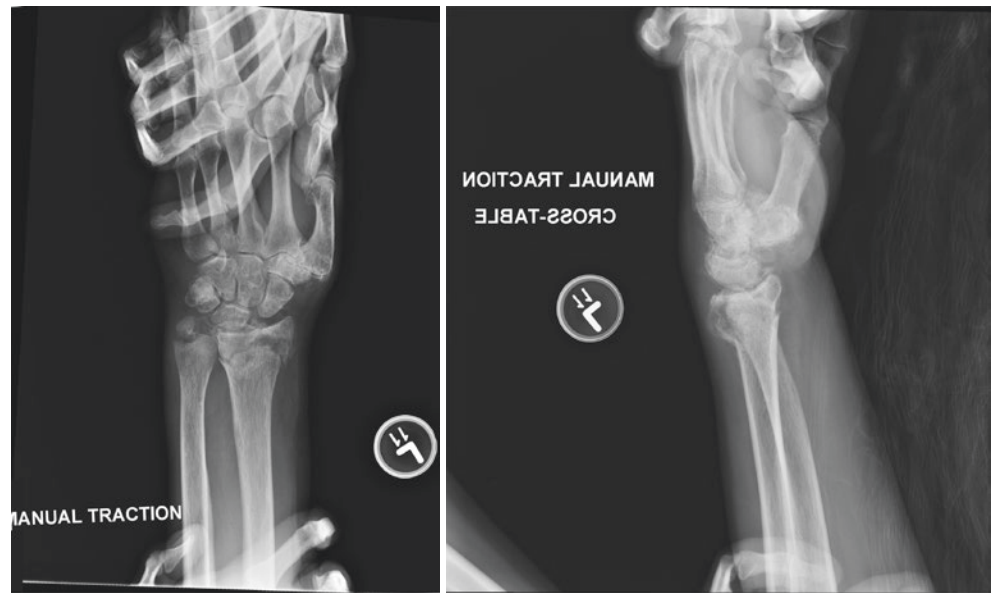
**Fig. 24.53** Final radiographs with slight dorsal tilt still present, without any functional limitations



**Fig. 24.54** Injury radiographs of intra-articular left distal radius fracture



**Fig. 24.55** Traction radiograph demonstrating improved alignment

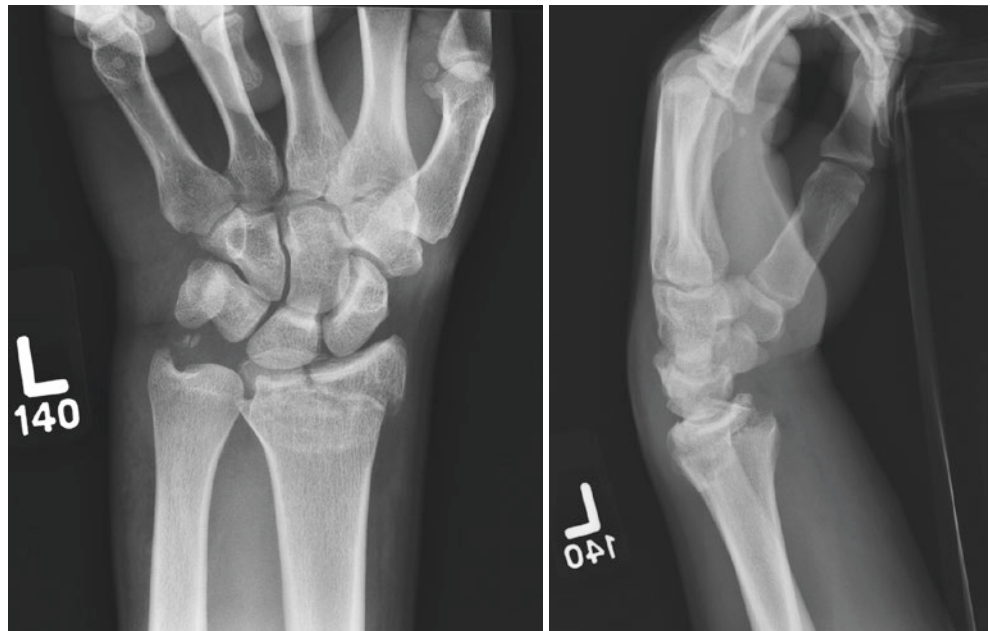


**Fig. 24.56** Intraoperative radiograph following external fixation and closed reduction

**Fig. 24.57** Radiographs following removal of external fixation



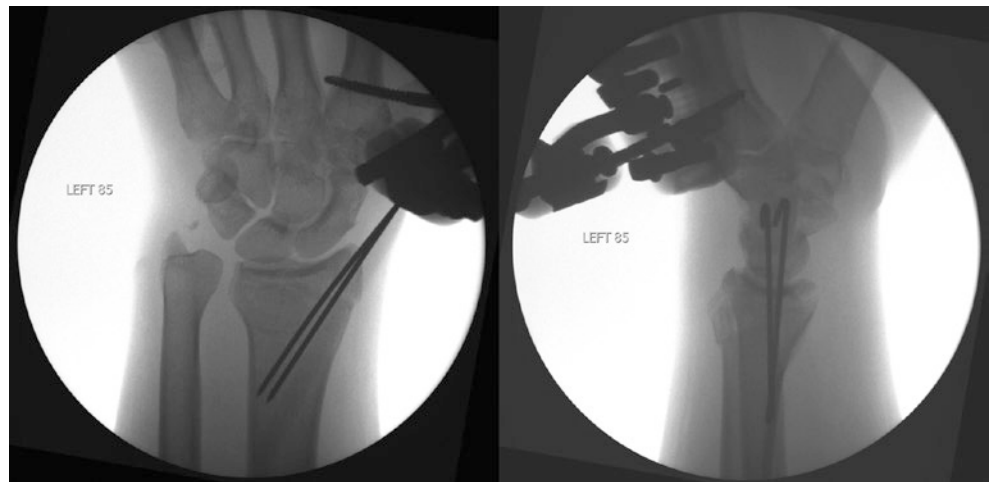
**Fig. 24.58** Injury radiographs of displaced intra-articular distal radius fracture



**Fig. 24.59** Traction radiographs demonstrate joint reduction, but dorsal translation is still present. Fractures are very distal, complicating fixation and soft tissue preservation for open reduction



**Fig. 24.60** Intraoperative radiographs of external fixation. Note extension of wrist, anterior translation of carpus with percutaneous fixation





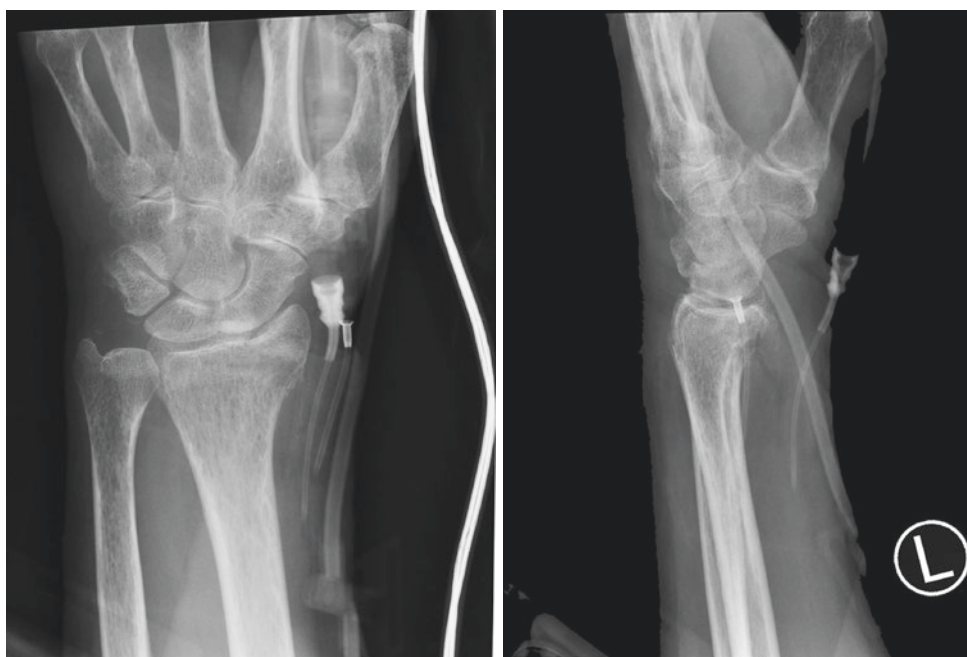
**Fig. 24.61** Radiographs on discharge



### 24.3.3 Surgical Options: Percutaneous Fixation

Percutaneous pins may be used individually, with external fixation, and with ORIF. I use 0.0625-in. Kirschner wires (K-wires). I endeavor to place these at the tip of the radial styloid, coursing obliquely to engage the ulnar cortex. There is a tendency to place these pins too transversely into the

metaphyseal and comminuted bone. I do not make individual incisions, and I use at least two, if not three, K-wires. If there is intra-articular involvement, I use a 0.045-in. K-wire in a transverse mode. Again, I will use this either individually or with external fixation, and occasionally with internal fixation. I see no need to connect the exposed ends with a clamp system (Figs. 24.62, 24.63, 24.64, 24.65, 24.66, 24.67, and 24.68).



**Fig. 24.62** Injury radiographs of left wrist with minimal displacement

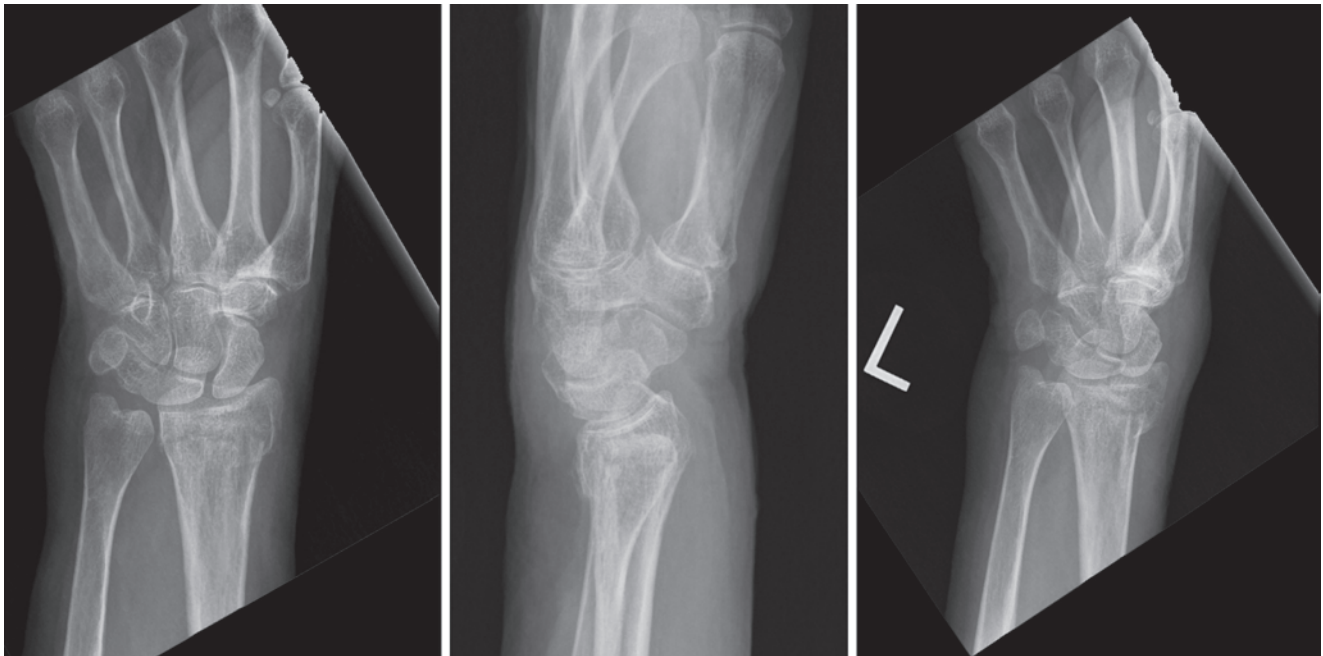
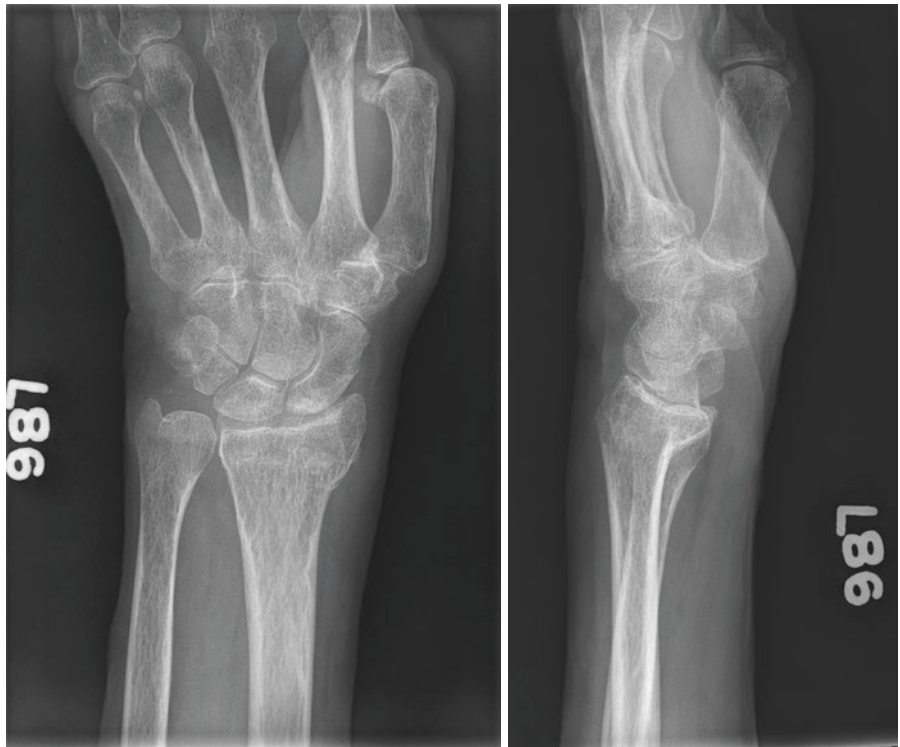
**Fig. 24.63** Radiographs of right wrist



**Fig. 24.64** Percutaneous K-wire fixation performed to allow use of left arm and hand because of limitations relative to right wrist



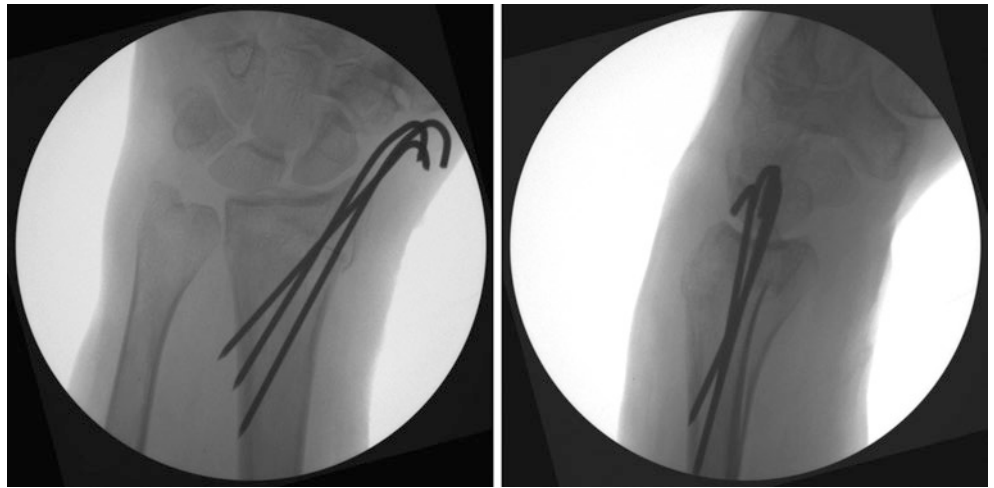
**Fig. 24.65** Final radiographs demonstrating slight increase in palmar tilt. Patient had no limitations or complaints



**Fig. 24.66** Injury radiographs reflecting dorsal tilt with anterior cortex aligned. Restoration of palmar tilt is required; intra-articular fracture is present



**Fig. 24.67** Intraoperative radiographs of reduction and percutaneous fixation, which was followed by casting for 4 weeks, with K-wire removal at 6 weeks



**Fig. 24.68** Radiographs at time of discharge

### 24.3.4 Surgical Options: ORIF with Plates

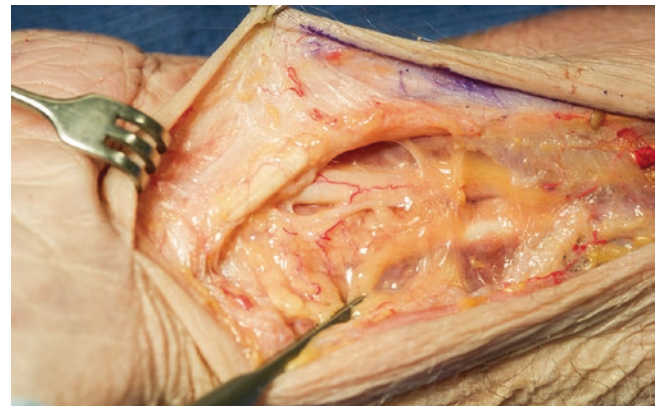
ORIF has become more common with the use of locking plates specifically designed for the distal radius. The design of the distal radius plate has become very complex; I feel that they are almost over-engineered. Numerous projects have studied distal radius plates from a biomechanical perspective in an effort to define a superior plate. The transition of plate superiority from the lab to the clinical arena may have limited efficacy [39–46]. The optimal plate, I believe, should be stainless steel, a simple T, with a single row of screws/pegs with locking options, but not of variable angle. My plate choices for extra-articular or nondisplaced intra-articular fractures were the now-discontinued Synthes 2.4-mm and 2.7-mm stainless steel plates; now I use the extra-articular 2.4-mm locking plate. Despite literature demonstrating the biomechanical weakness of the earlier plate, it performed very well for decades with no apparent failures. I do not like titanium because of screw head stripping and difficulty in contouring. Most titanium plates are

double-rowed, which I feel is unnecessary, and I do not like the Y or broad plates because they block fracture line visualization.

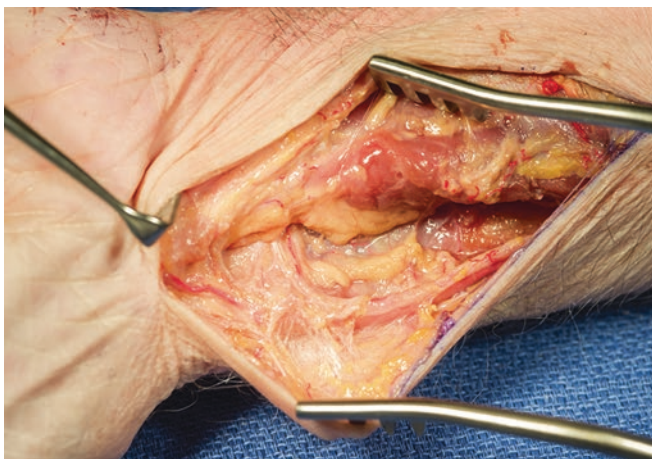
The approach to the distal radius anteriorly is from the wrist crease, proximally between the flexor carpi radialis (FCR) and the radial artery. I do not open the FCR sheath, as I believe adequate visualization can be gained without opening the sheath and that it is not necessary to go through the sheath to protect the radial artery. I believe you should be able to work around the artery, protect it, dissect only one interval, and not skeletonize the artery and retract it away. I have had no problems getting access to the radial or ulnar side with this technique. I do not cross the wrist crease. The FCR and flexor pollicis longus are retracted, and the pronator quadratus is elevated from radial to ulnar with a small cuff of the brachioradialis, which will be used for subsequent repair (Figs. 24.69, 24.70, 24.71, 24.72, and 24.73). There have been a couple of studies concerning the reapproximation of the pronator quadratus, which report that repair may not be indicated or necessary [47, 48].



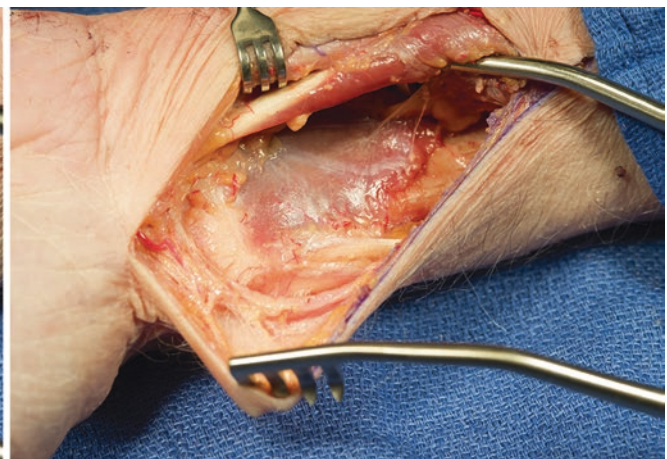
**Fig. 24.69** Incision from wrist crease proximally about 10 cm, centered over the interval between the flexor carpi radialis (FCR) and radial artery



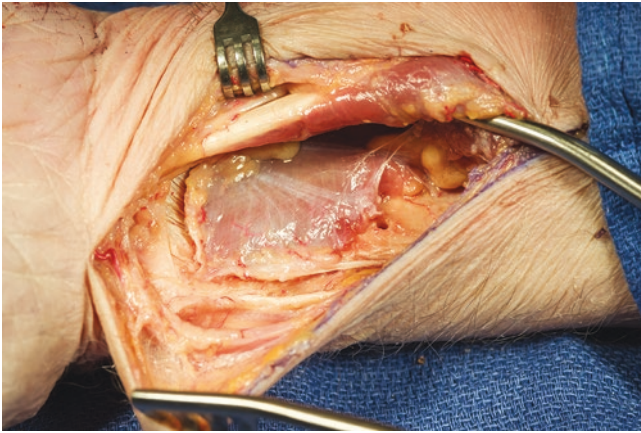
**Fig. 24.70** FCR retracted, exposing the median nerve and palmar cutaneous nerve beneath the FCR (arrow)



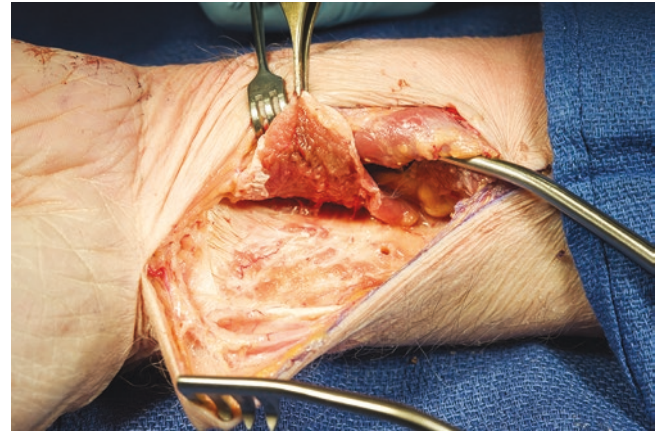
**Fig. 24.71** Approach and exposure of the pronator quadratus







**Fig. 24.72** Incising the pronator quadratus, including a portion of the brachioradialis, for purposes of closure after fixation

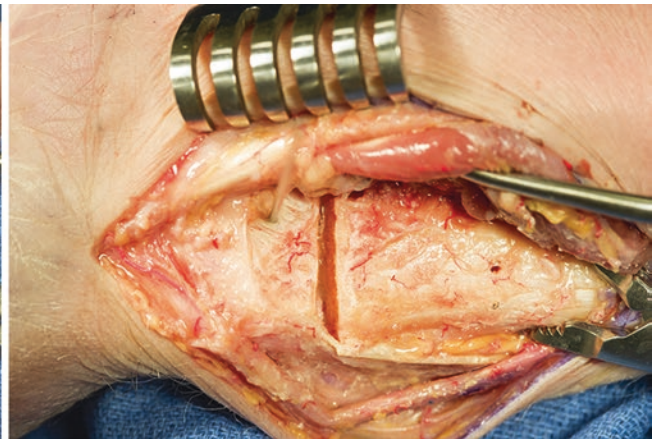
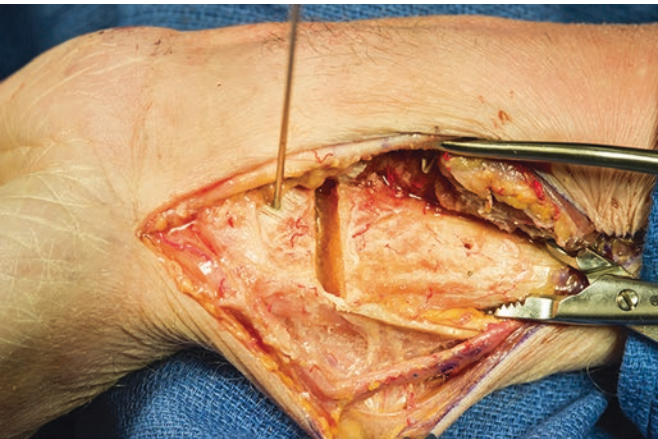
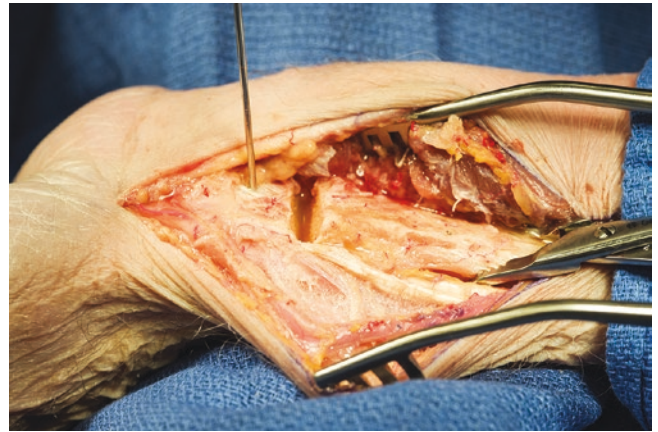


**Fig. 24.73** Pronator quadratus elevated

The fixation of the distal fragment, if it is in fact extra-articular, is frequently begun with preplacement of a K-wire oriented parallel to the joint, and this is used for the subsequent reduction maneuver. The reduction can be performed, manually held, and followed by plated fixation, correcting

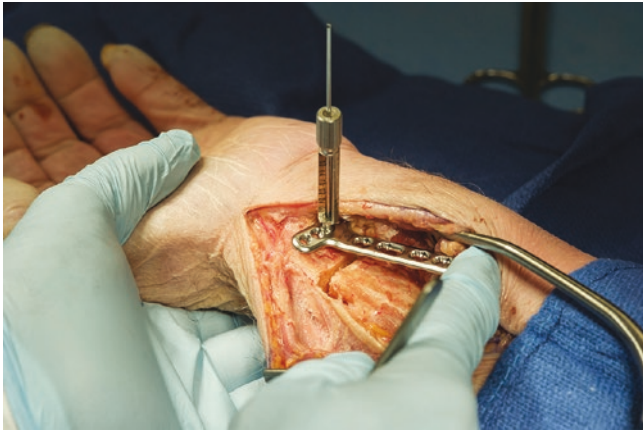
for palmar tilt, or K-wire fixation through the styloid or through the anterior rim (Figs. 24.74, 24.75, 24.76, 24.77, 24.78, 24.79, 24.80, 24.81, 24.82, 24.83, 24.84, 24.85, 24.86, 24.87, and 24.88).

**Fig. 24.74** Fracture simulation, osteotomy with 0.0625-in. K-wire inserted for distal plate fixation first, then reducing the distal fragment to the shaft



**Fig. 24.75** K-wire manipulation demonstrating fracture reduction





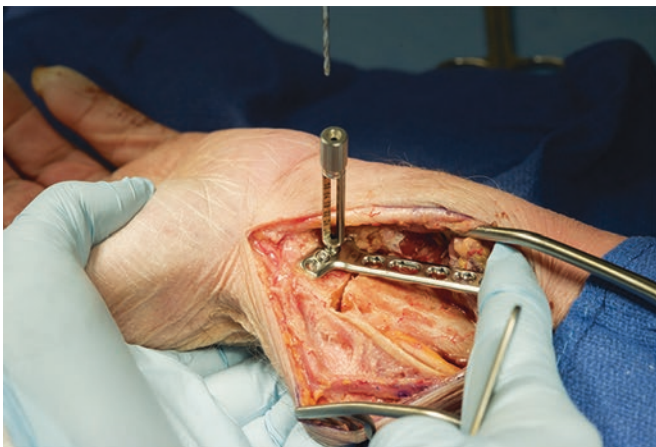
**Fig. 24.76** Plate and guide placed over K-wire



**Fig. 24.77** 1.8-mm drill bit for cortical screw adjacent to locking screw to secure plate flush with distal radius



**Fig. 24.78** 2.4-mm cortical screw insertion seating plate to bone



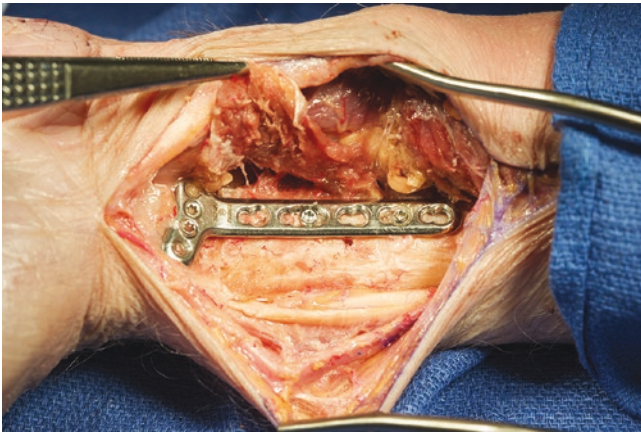
**Fig. 24.79** K-wire removal and hole drilled for locking screw. Note that the stem of the plate is still not delivered to the shaft of the radius



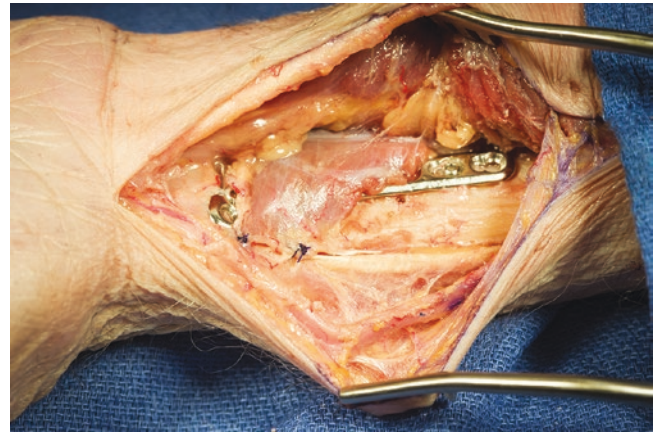
**Fig. 24.80** 2.4-mm locking screw inserted



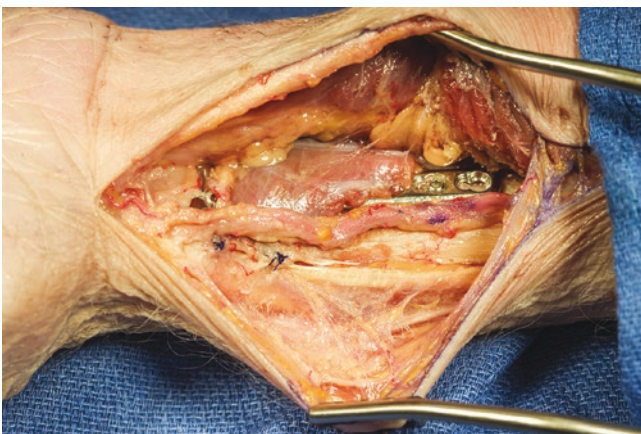
**Fig. 24.81** After at least two locking screws in distal fragment, the plate is seated on the shaft with a cortical screw



**Fig. 24.82** Plate secured to radius. In a clinical scenario, at least four screws distal and proximal would be used



**Fig. 24.83** Pronator quadratus repaired to brachioradialis. Leaving a portion of the brachioradialis on the pronator improves suture purchase



**Fig. 24.84** Advantage of not skeletonizing the radial artery: it prevents the artery from falling into the field



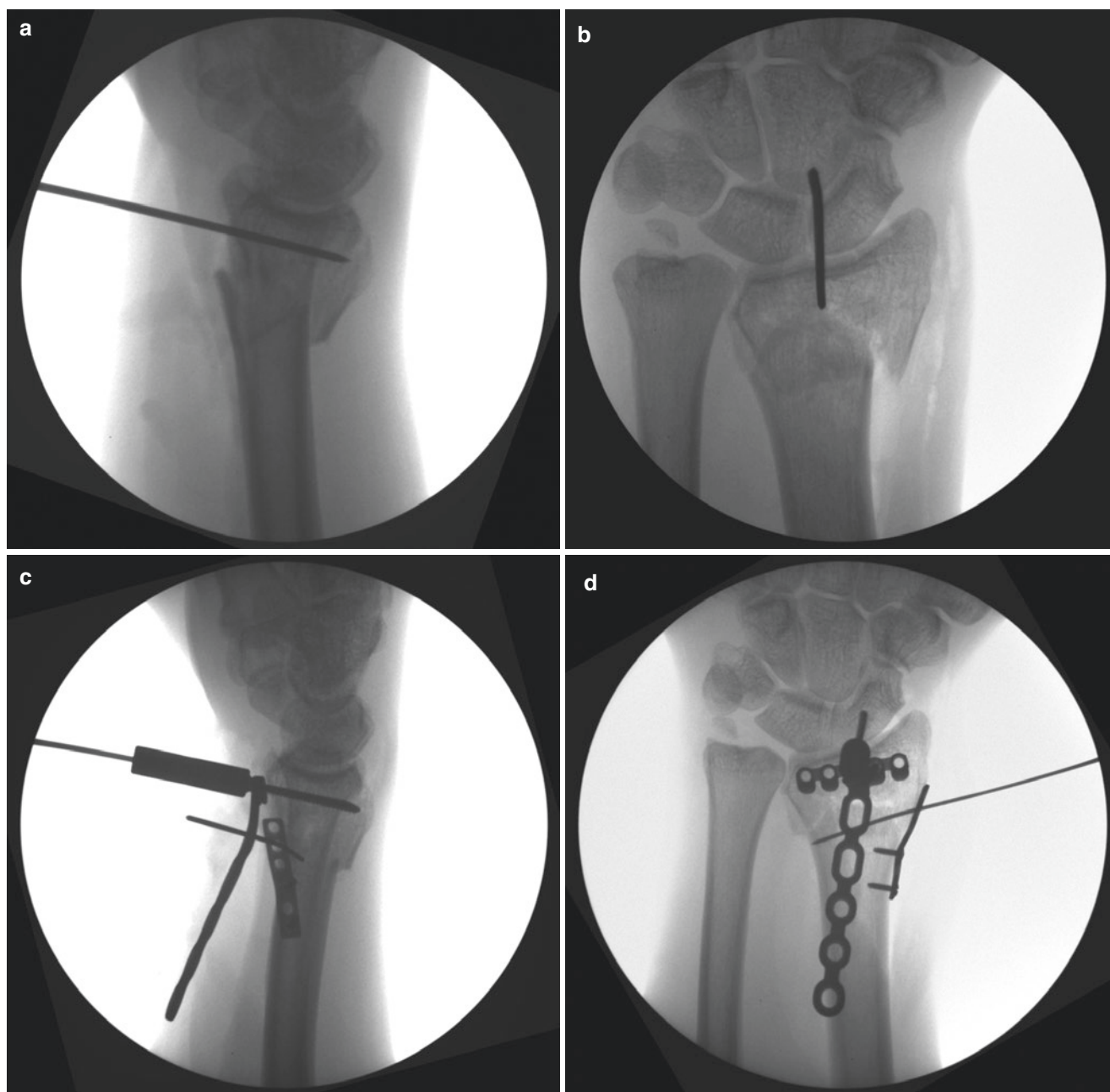
**Fig. 24.85** Injury radiographs of a right distal radius fracture with dorsal intra-articular comminution



**Fig. 24.86** Splinting radiograph demonstrates acceptable alignment, but still dorsally translated

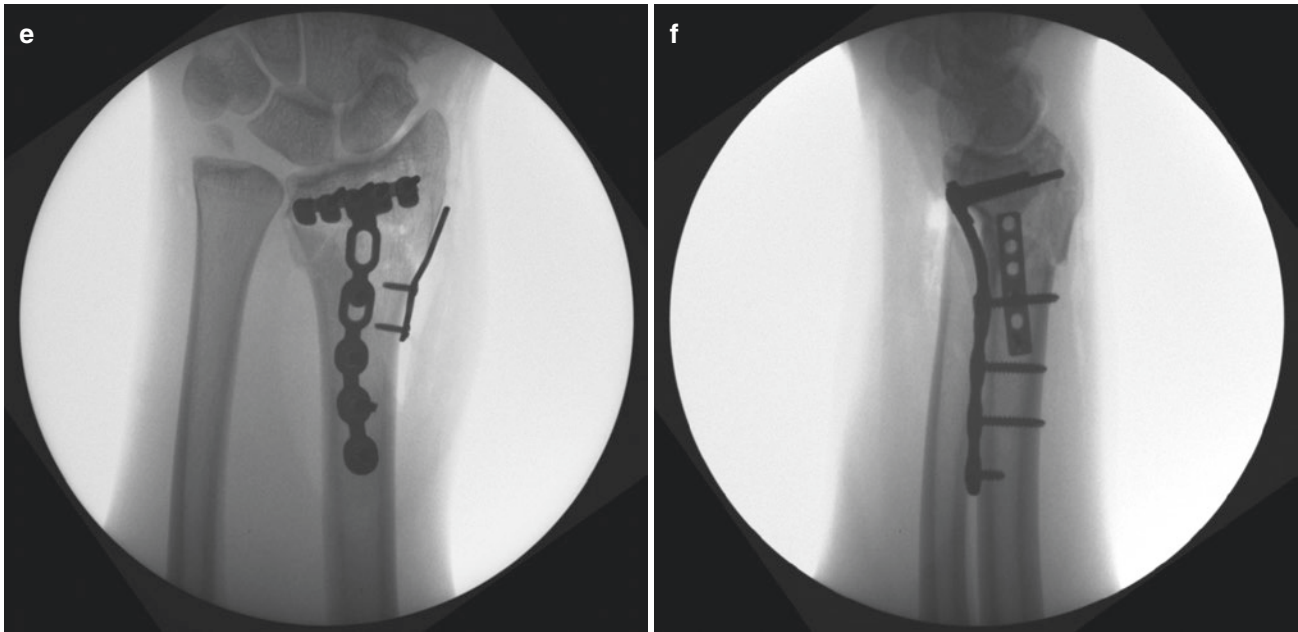




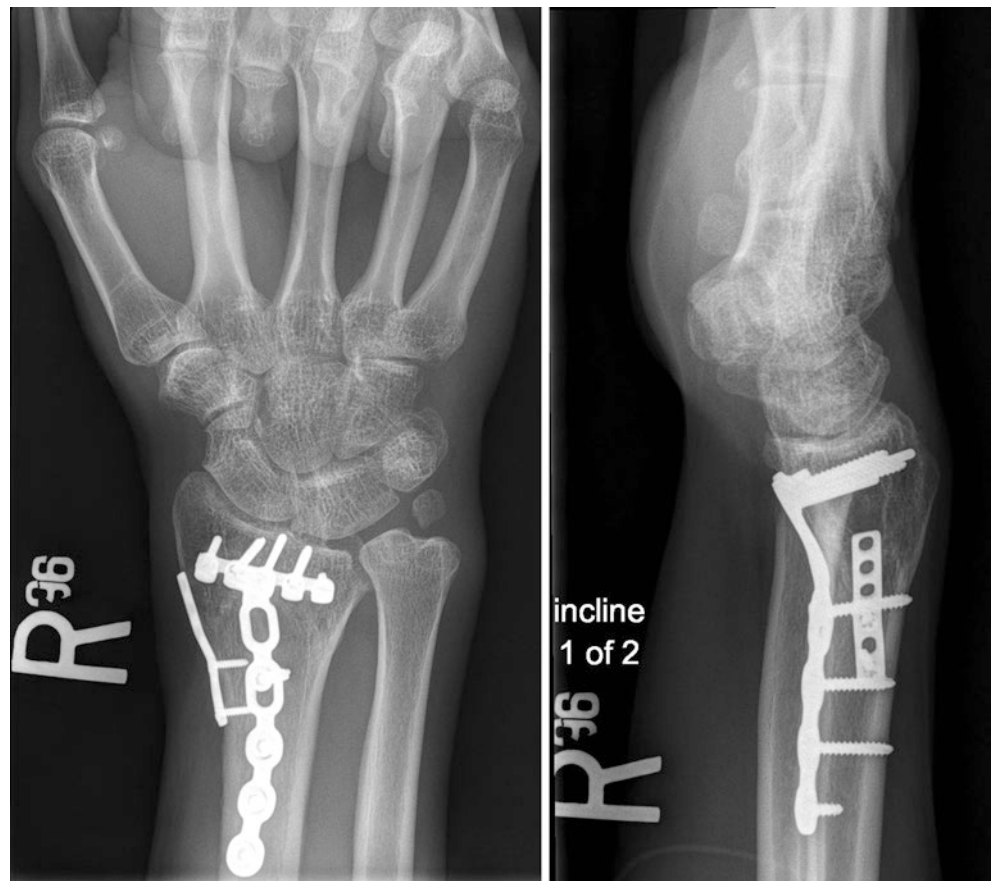


**Fig. 24.87** (a) Intraoperative sequence of ORIF using a plate as a reduction device after localizing K-wire insertion and buttressing the first-compartment plate to resist radial translation. (b) AP intraoperative radiograph checking K-wire position. (c) Intraoperative lateral

radiograph following distal fixation of plate. (d) AP radiograph. (e) AP radiograph following reduction with plate. (f) Intraoperative lateral radiograph demonstrating reduction and palmar tilt restoration



**Fig. 24.87** (continued)



**Fig. 24.88** Final radiographs at discharge

If the fracture is intra-articular, requiring fragment joint visualization, the joint reduction cannot be performed from an anterior approach because of the radioscaphocapitate ligament and the long radiolunate ligament. A dorsal approach is required for the intra-articular fracture. Therefore, the sequence is this: The anterior approach allows reduction of the palmar ulnar corner fragment, along with mini-fragment plate fixation, which is followed by the

dorsal approach. When addressing intra-articular fractures, it is important to re-establish the palmar ulnar corner (or the sustentaculum lunatum [49]), as this fragment reduction restores the length and tilt and the subsequent joint reconstruction from the dorsal approach (Figs. 24.89, 24.90, 24.91, 24.92, 24.93, 24.94, 24.95, 24.96, 24.97, 24.98, 24.99, 24.100, and 24.101).



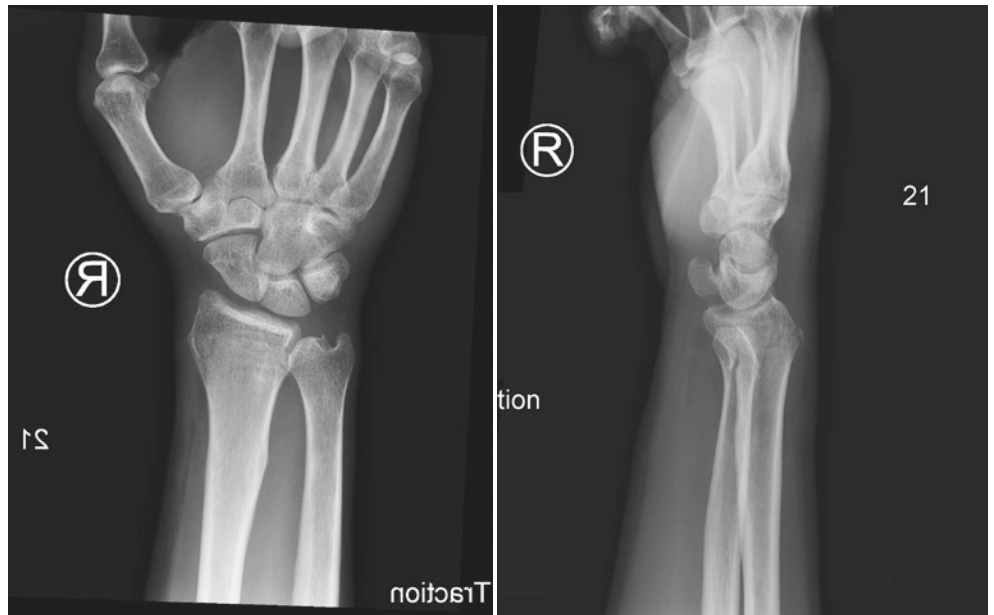
**Fig. 24.89** Injury radiographs reflecting anterior translation of right distal radius and carpus on forearm (arrow). The patient sustained bilateral distal radius fractures



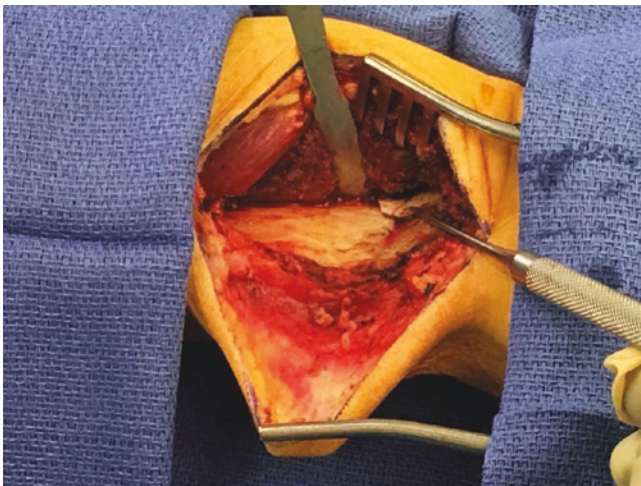
**Fig. 24.90** Radiographs of left distal radius radial styloid fracture that is transverse in nature, reflecting probable tension injury



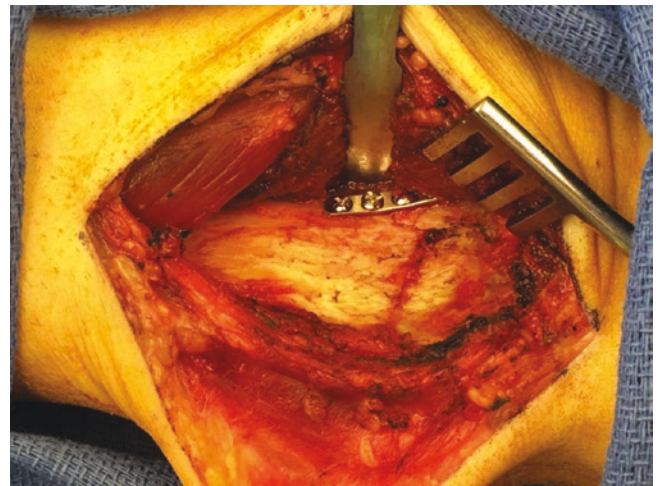
**Fig. 24.91** Traction radiographs with improved alignment



**Fig. 24.92** Splinting radiographs with persistent anterior translation

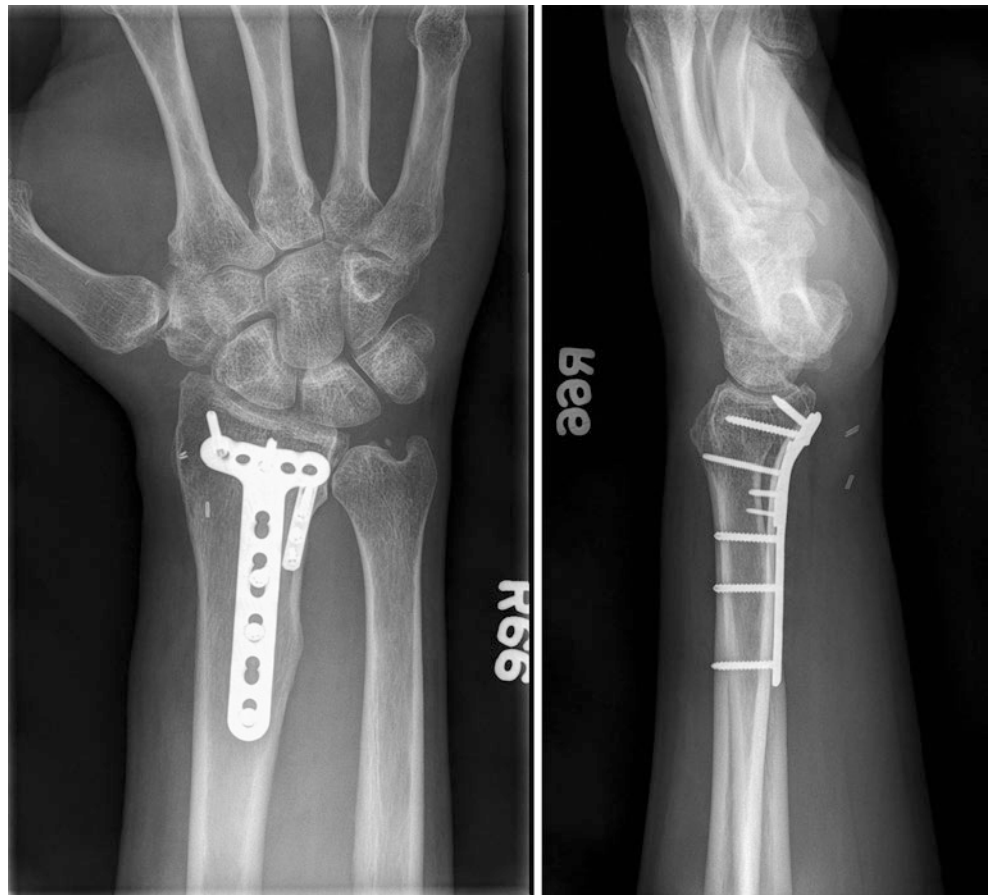


**Fig. 24.93** Anterior approach with palmar ulnar corner displaced



**Fig. 24.94** Fixation of fragment

**Fig. 24.95** PA radiographs following ORIF of right distal radius



**Fig. 24.96** Radiographs following percutaneous fixation of left distal radius

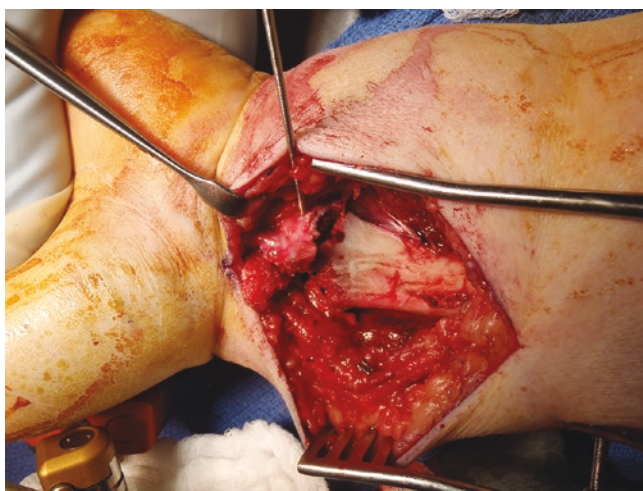




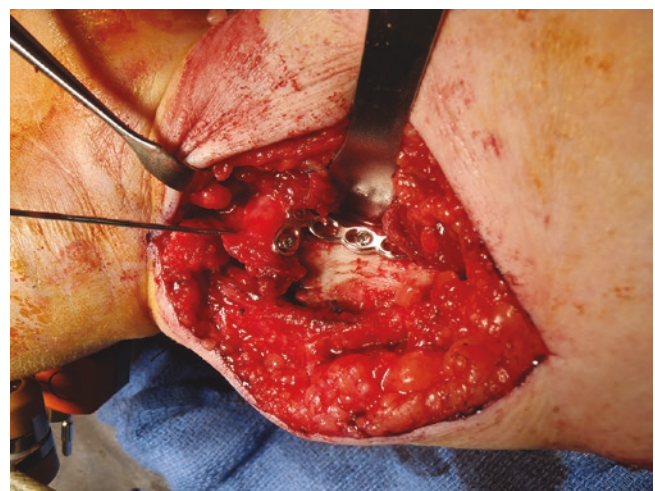
**Fig. 24.97** Injury radiographs of left distal radius fracture



**Fig. 24.98** *Left*, Lateral traction radiographs demonstrating V sign with dorsal fragment (*black arrow*) and palmar fragment (*white arrow*) rotated distally. The implication is that anterior and posterior approaches will be required, reflecting soft tissue disruption between the metaphysis and articular fragment. *Right*, AP traction radiographs

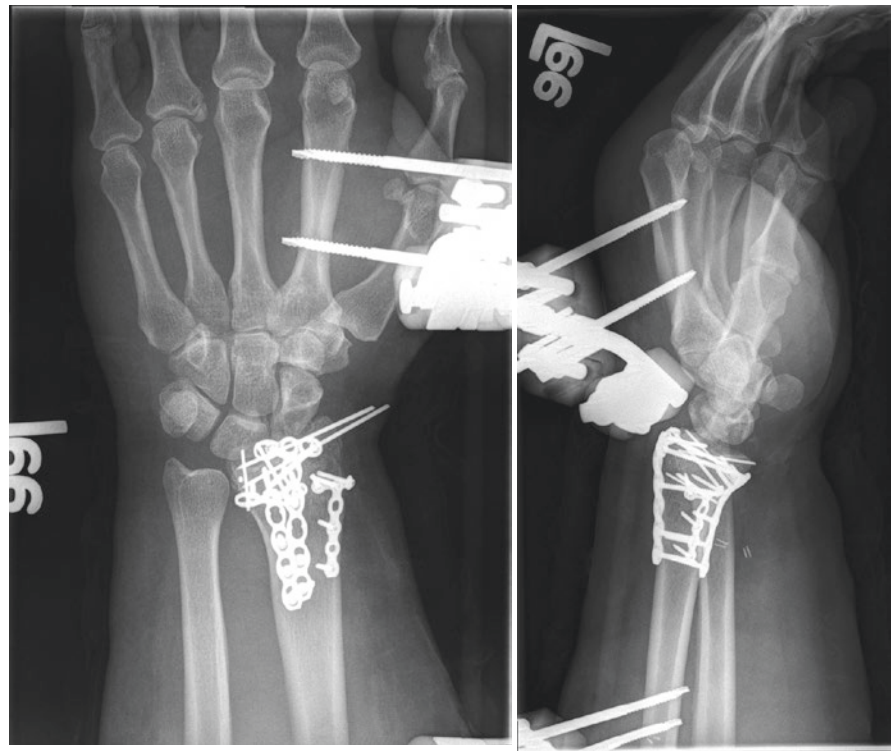


**Fig. 24.99** Threaded Steinmann pin in palmar ulnar corner fragment for manipulation purposes



**Fig. 24.100** Fixation of fragment in buttress made to correct for anterior translation

**Fig. 24.101** Radiographs following fixation



The dorsal approach is midline over Lister's tubercle. Because of the comminution, Lister's tubercle frequently cannot be ascertained. Use the interval between the index and long metacarpal as a guide. If you review a film without

a fracture, you will notice that this joint effectively guides you down to the scapulolunate joint, Lister's tubercle, and down the mid-axis of the radius (Fig. 24.102).

**Fig. 24.102** *Left*, Line representing interval between index and long metacarpals, pointing to Lister's tubercle. *Right*, Skin incision outlined for dorsal approach to distal radius. Circle represents Lister's tubercle. If the tubercle cannot be palpated, draw a line from the interval between the radius and long metacarpal for a midline incision



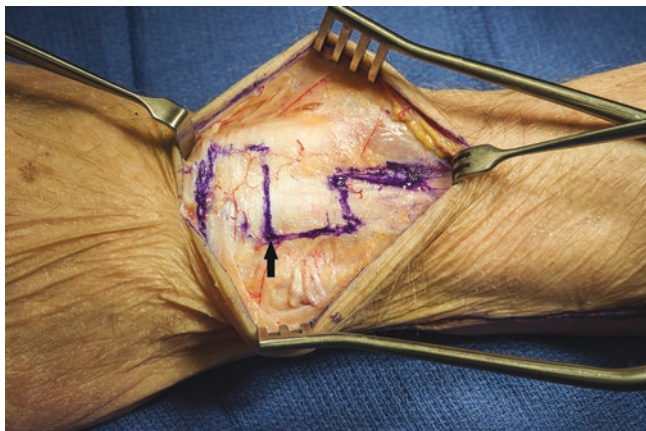
The incision extends from approximately the mid-carpus to the metadiaphyseal region. The extensor retinaculum is visualized. Double rectangular flaps are now developed with the transverse limb at the radiocarpal joint (Fig. 24.103). The longitudinal proximal limb is between the fourth and fifth

compartment. The distal radial longitudinal incision is between the second and third. The flaps are elevated. The distal flap is elevated, incorporating the fourth compartment with small tenosynovium on the undersurface of the extensor indicis proprius and extensor digitorum communis (EIP/EDC).

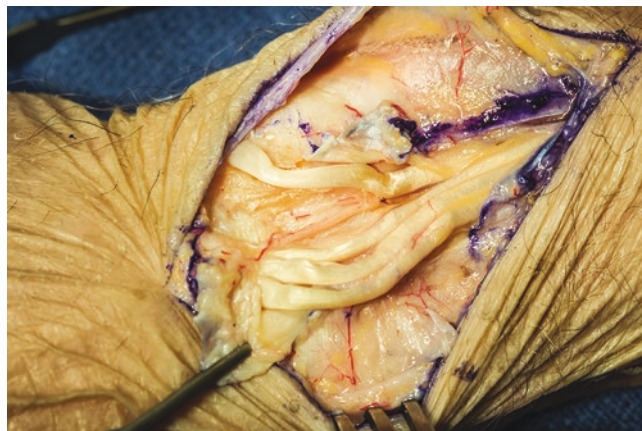


It is very important to preserve the dorsal radiotriquetral ligament complex, as this will also help to prevent a palmar intercalated segmental instability (PISI) deformity, acknowledging that preservation of the ligament complex alone will not prevent PISI, but it is a portion of the potential ulnar

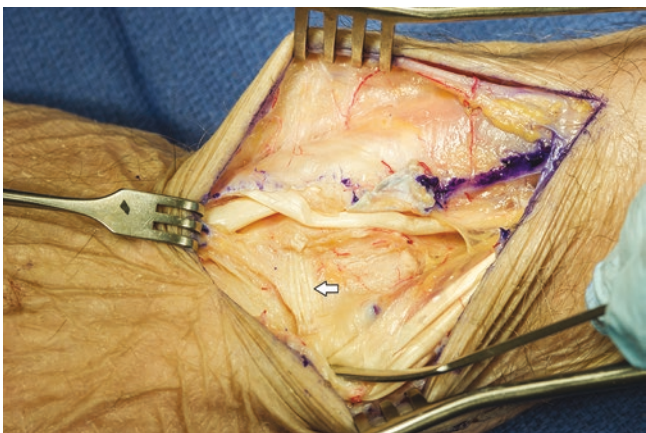
translocation instability (Figs. 24.104, 24.105, and 24.106). The dorsal radiotriquetral ligament is frequently attached to the fourth compartment Lister's tubercle fragment, except in radiocarpal fracture dislocations, where we find it still frequently attached to the large radial styloid fragment.



**Fig. 24.103** Double rectangular flaps outlined with transverse line at the radiocarpal joint (arrow). Use palpation of the ulnar head to localize



**Fig. 24.104** Flaps elevated with extensor pollicis longus and proximal flap retracted radially and the extensor digitorum communis and extensor indicis proprius retracted ulnarly with investing tenosynovium deep to extensors



**Fig. 24.105** Dorsal radiotriquetral ligament identified and not cut (arrow)



**Fig. 24.106** Capsular reflection radially developed between the dorsal radiotriquetral ligament and the scaphotriquetral ligament

Sometimes the dorsal ligaments are completely avulsed off the dorsal distal radius and are reinserted through drill holes. The second compartment is elevated and the EPL is mobilized out of the third compartment, but is usually not transposed when the closure is subsequently performed, as shown by Shah et al. [50], as this will decrease subsequent pinch strength because of the loss of the adduction movement.

Fixation is carried out with a number of modalities, including K-wires, interosseous wires, plates, and screws

(Figs. 24.107, 24.108, 24.109, 24.110, 24.111, 24.112, 24.113, 24.114, 24.115, 24.116, 24.117, 24.118, 24.119, 24.120, 24.121, 24.122, 24.123, 24.124, 24.125, 24.126, 24.127, 24.128, 24.129, and 24.130). The stabilization begins with the palmar ulnar corner fragment, if so required. The dorsal fragments are reduced to the anterior rim palmar fragments, frequently with multiple K-wire fixation. There is usually a gap dorsally in the metaphysis requiring bone grafting. My bone graft of choice is cancellous allograft.



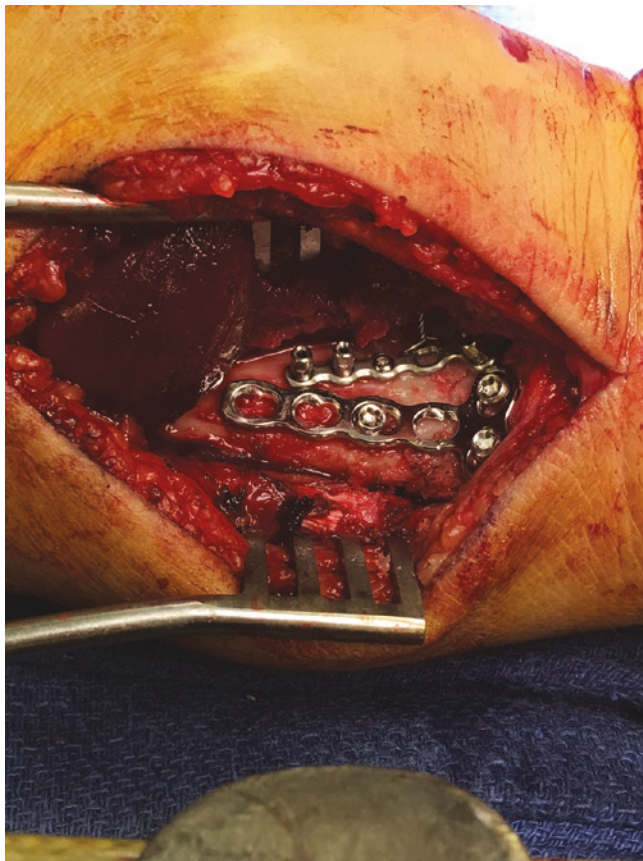
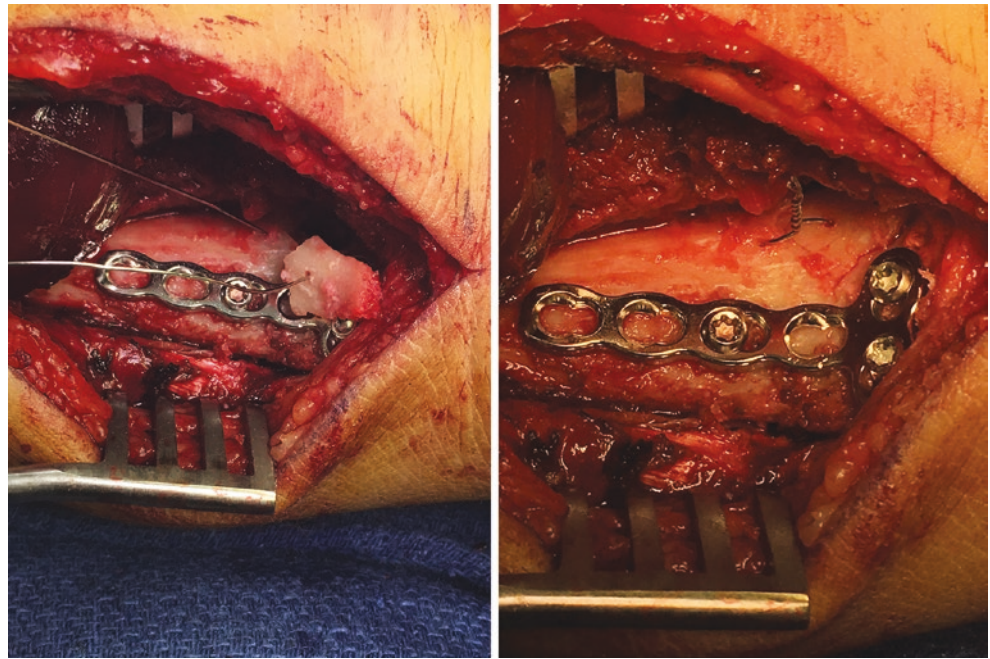
**Fig. 24.107** Injury radiographs of right forearm demonstrating right distal radius fracture



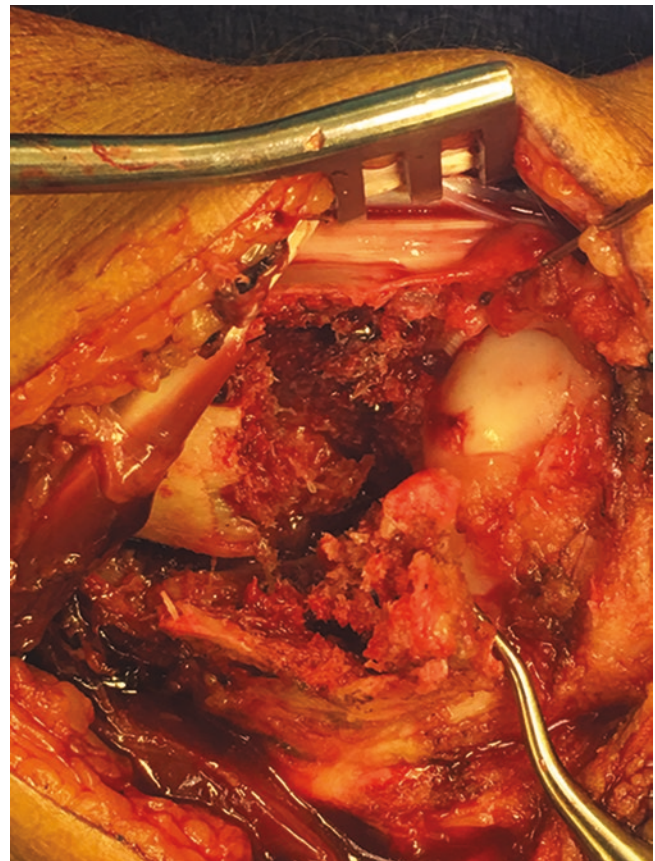
**Fig. 24.108** Traction radiographs with persistent intra-articular step-off



**Fig. 24.109** Anterior approach with metaphyseal palmar ulnar corner fragment reduction and fixation with interosseous wire



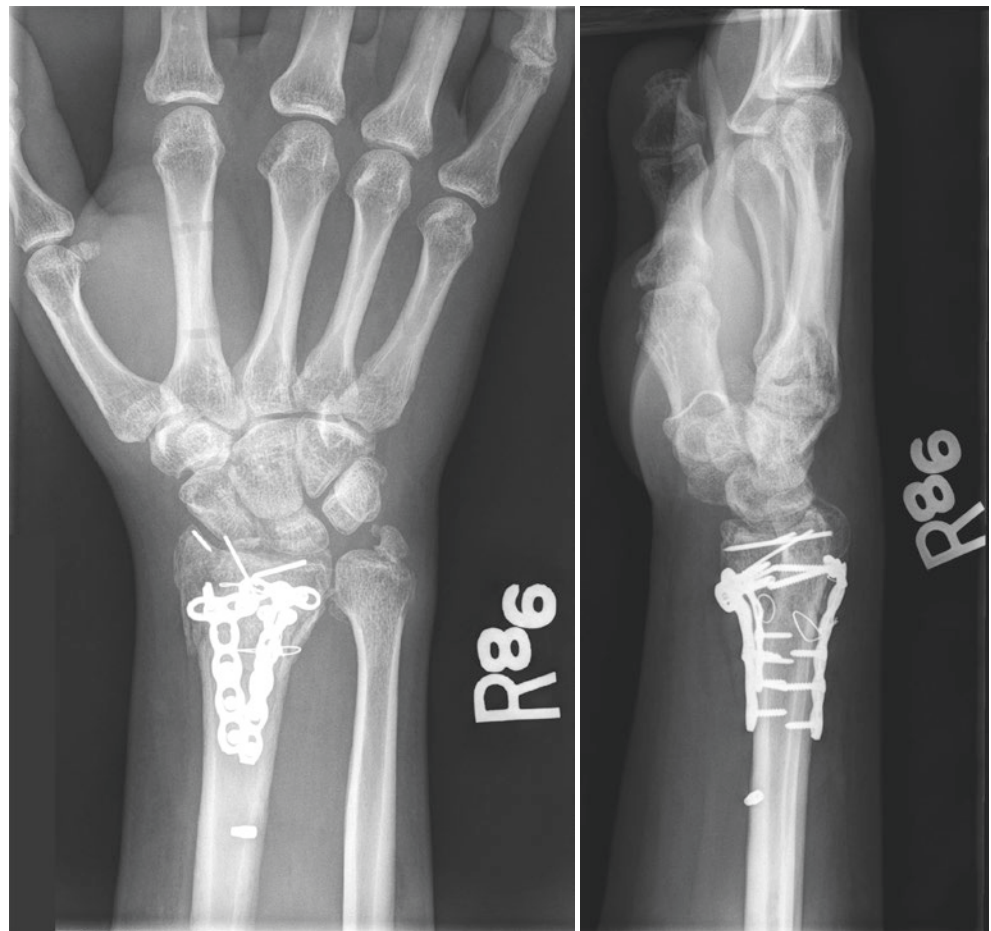
**Fig. 24.110** Final anterior fixation



**Fig. 24.111** Dorsal approach with defect in proximal pole of scaphoid (arrow)



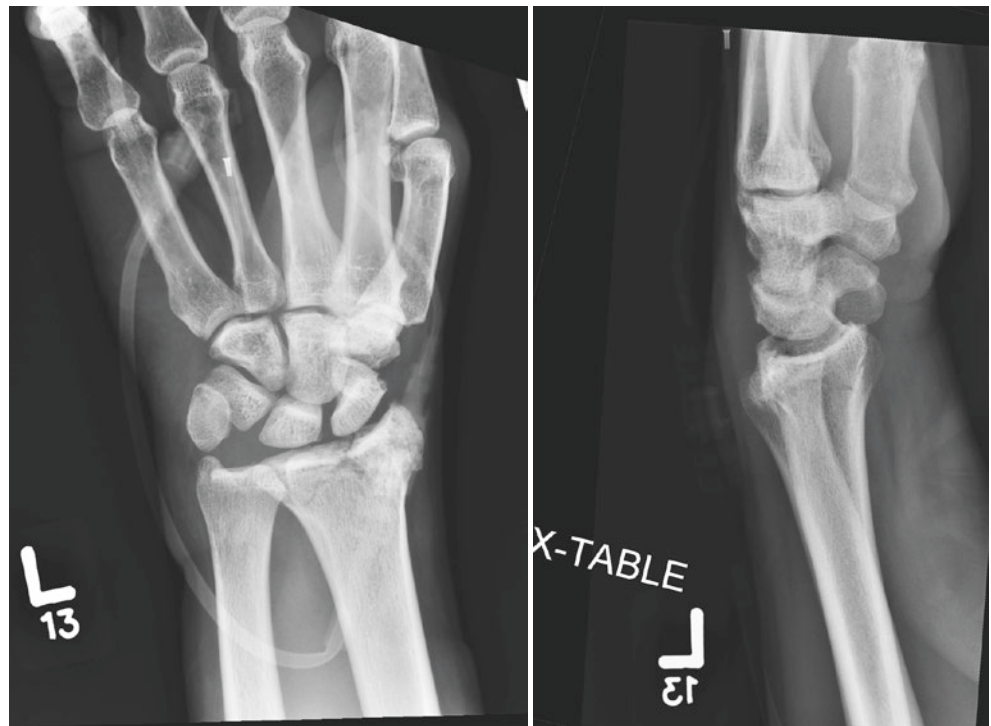
**Fig. 24.112** Radiographs following fixation. Note wandering locking plate guide



**Fig. 24.113** Radiographs following external fixation removal

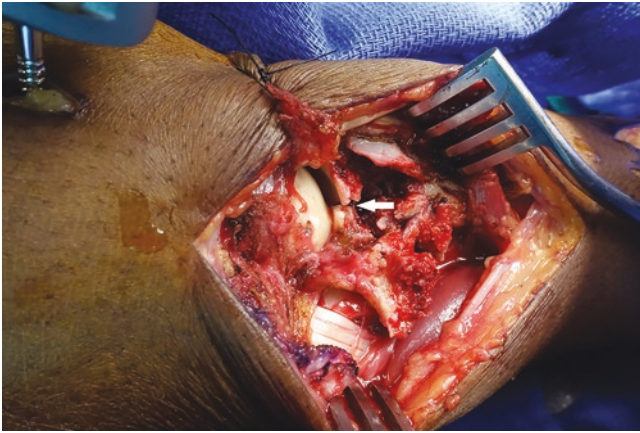


**Fig. 24.114** Injury radiographs of intra-articular left distal radius fracture

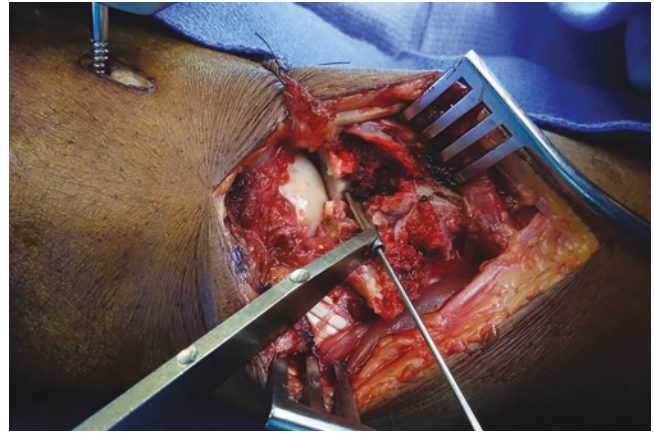


**Fig. 24.115** Traction radiographs of left distal radius fracture with persistent intra-articular step-off (*arrow*)

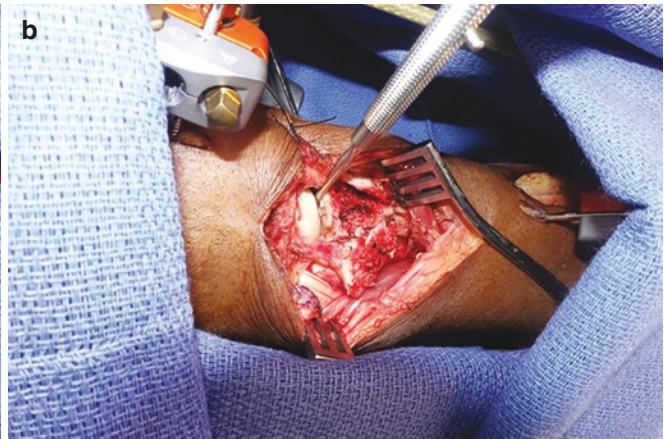
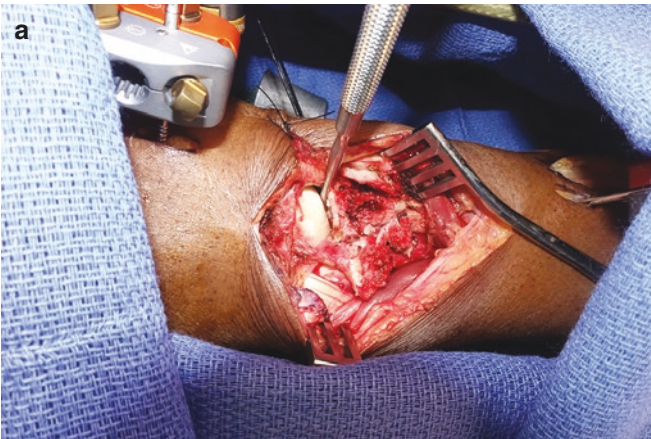




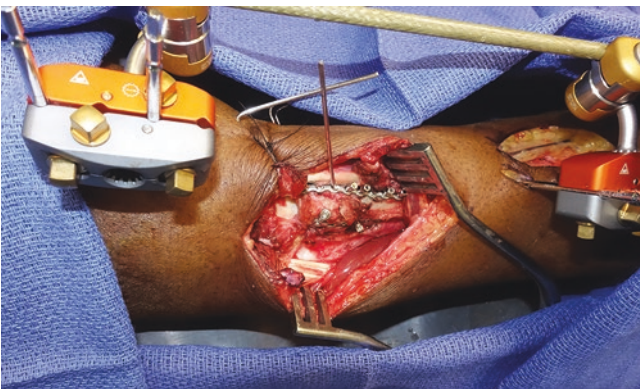
**Fig. 24.116** Dorsal approach reflecting intra-articular step-off (*arrow*)



**Fig. 24.117** Placement of inside-out K-wire prior to reduction

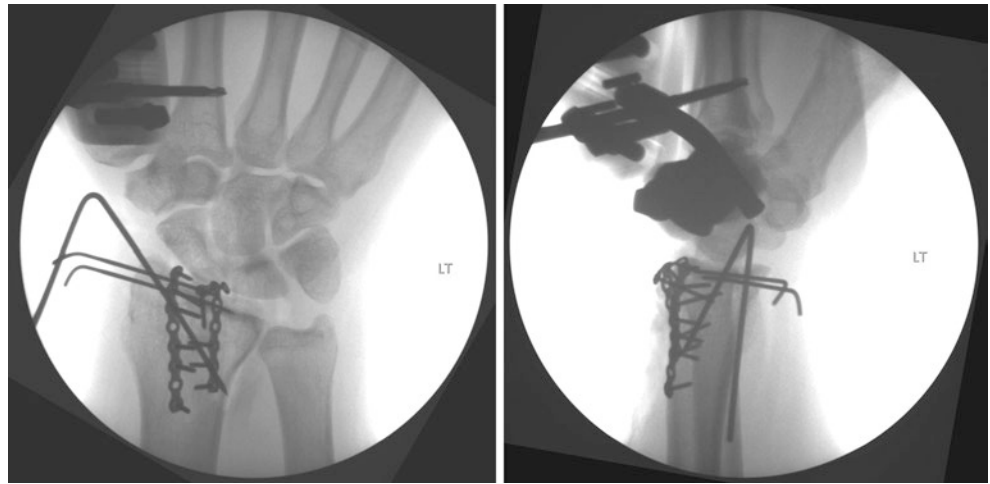


**Fig. 24.118** (a, b) Reduction of joint with fixation by two preplaced K-wires



**Fig. 24.119** Definitive fixation being performed with dorsal 1.5-mm locking plates, including Lister's tubercle fragment with dorsal radiotriquetral ligament attachment

**Fig. 24.120** Intraoperative radiographs following external fixation and internal fixation



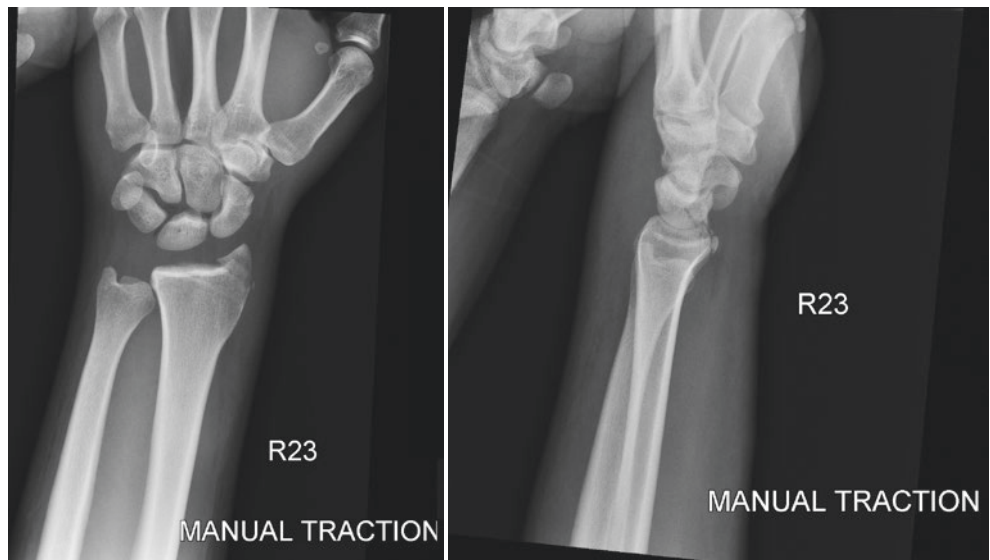
**Fig. 24.121** Follow-up radiographs following removal of external fixation and K-wires



**Fig. 24.122** Injury radiographs of right wrist demonstrating radial styloid fracture with carpal malalignment of dorsally tilted lunate

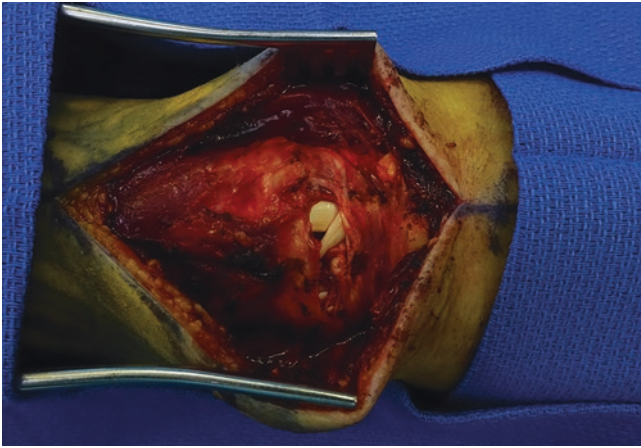


**Fig. 24.123** Traction radiographs with joint distraction

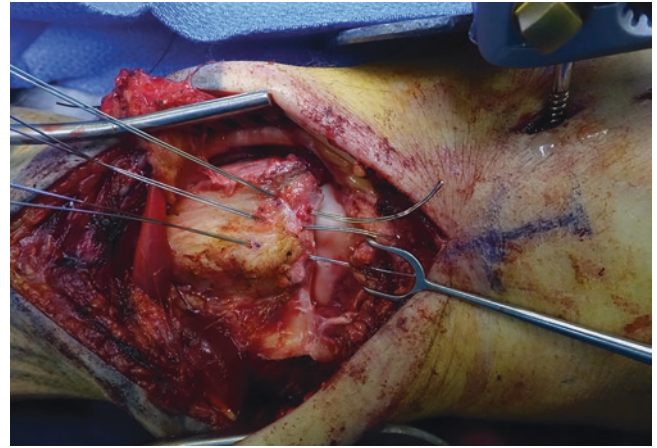


**Fig. 24.124** Stress radiographs demonstrating marked instability. Hand exposure noted

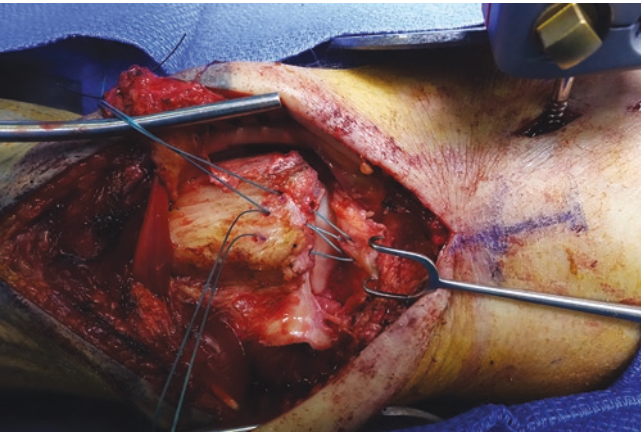




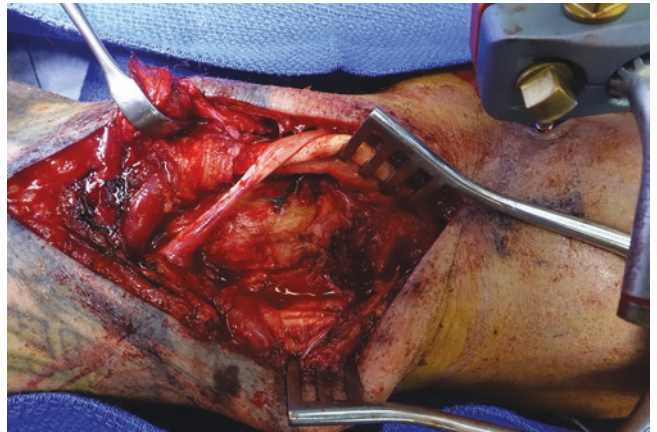
**Fig. 24.125** Dorsal approach with transverse rent in extensor retinaculum



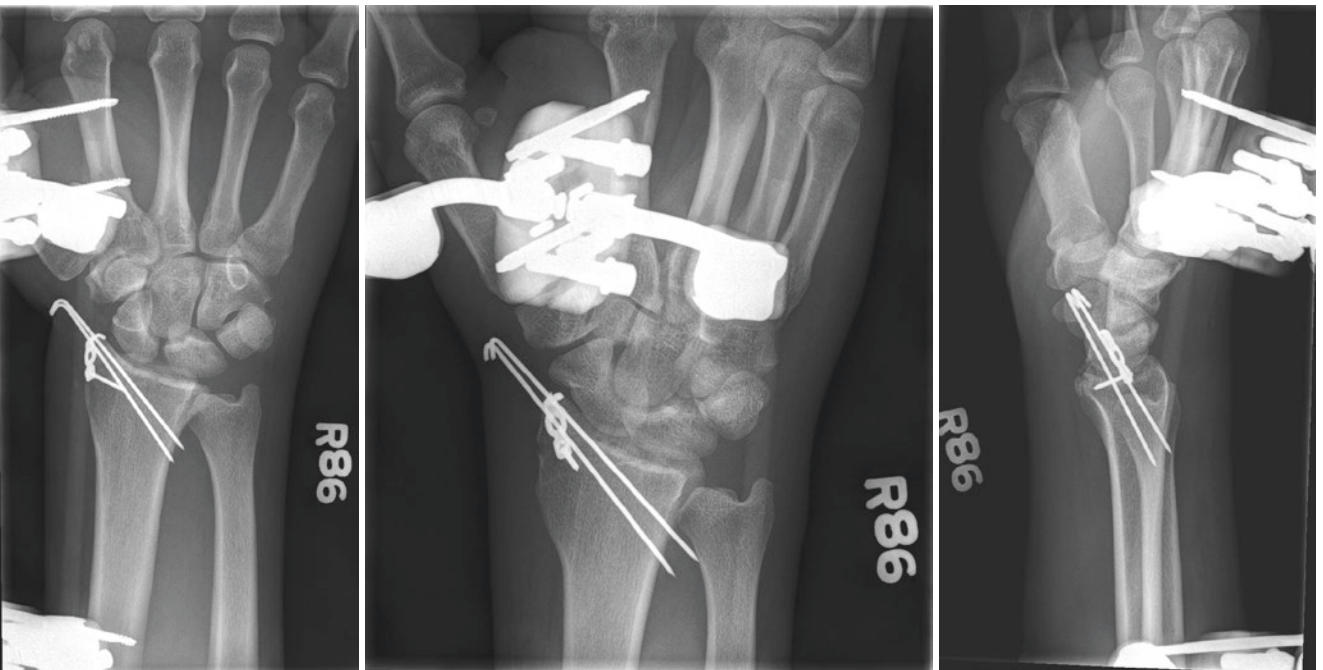
**Fig. 24.126** 24-gauge wires passed for sutures from capsule and dorsal ligament



**Fig. 24.127** 0-Ethibond Excel® sutures fed through holes in distal radius



**Fig. 24.128** Sutures tied after radial styloid fixation



**Fig. 24.129** Radiograph following ORIF, external fixation, percutaneous fixation, and ligament repair

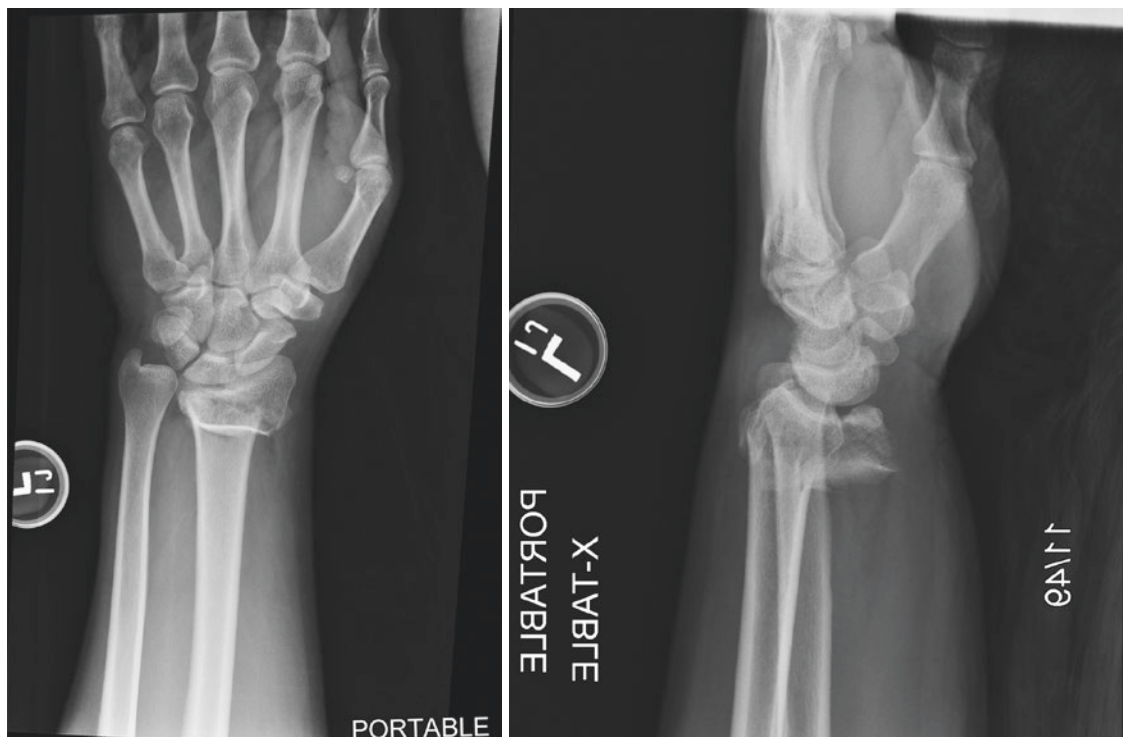


**Fig. 24.130** Radiographs at time of discharge



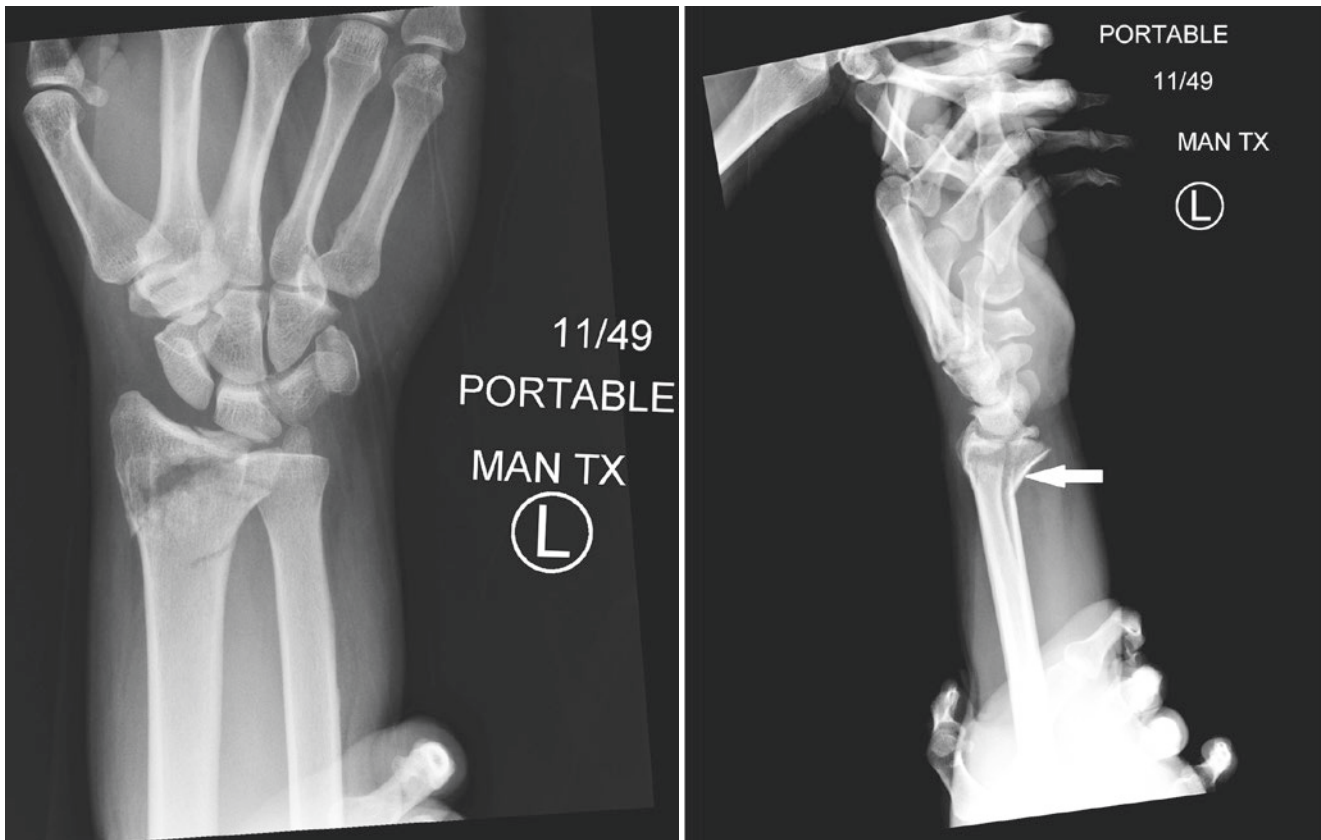
I began using autogenous bone graft (usually from the iliac crest) and then ventured into the bone substitutes, but I was completely unimpressed with any of the substitutes. The cancellous allograft has served me well, nicely filling voids,

and it incorporates nicely (Figs. 24.131, 24.132, 24.133, 24.134, 24.135, 24.136, 24.137, 24.138, 24.139, 24.140, 24.141, and 24.142).

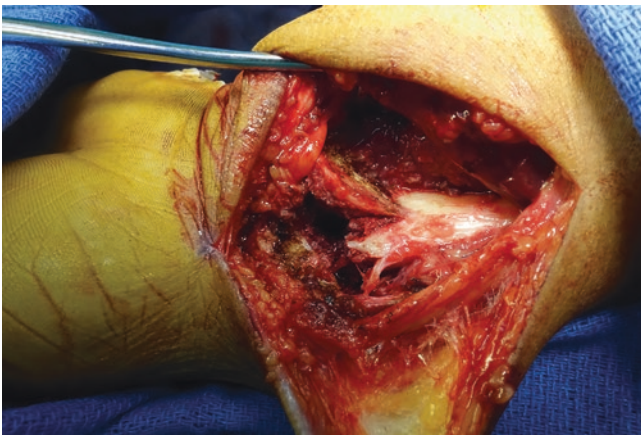


**Fig. 24.131** Injury radiographs of left distal radius fracture

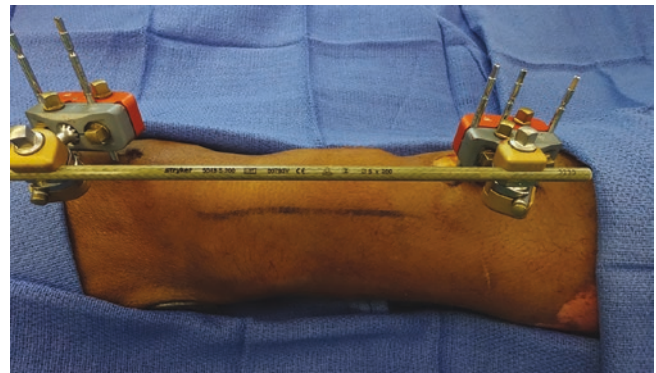




**Fig. 24.132** Traction radiographs demonstrating segmental component to palmar ulnar corner fragment

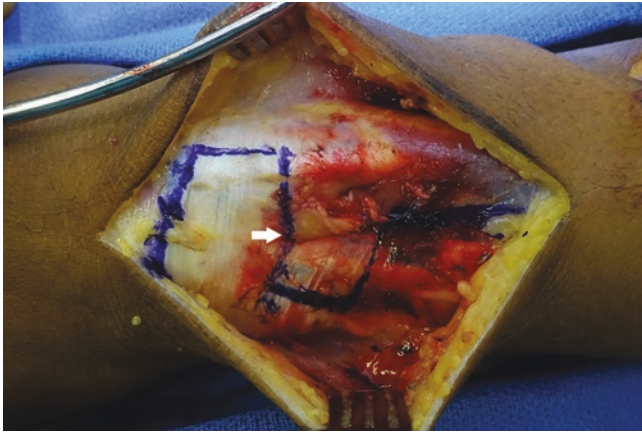


**Fig. 24.133** Anterior approach demonstrating segmental palmar ulnar corner fragment

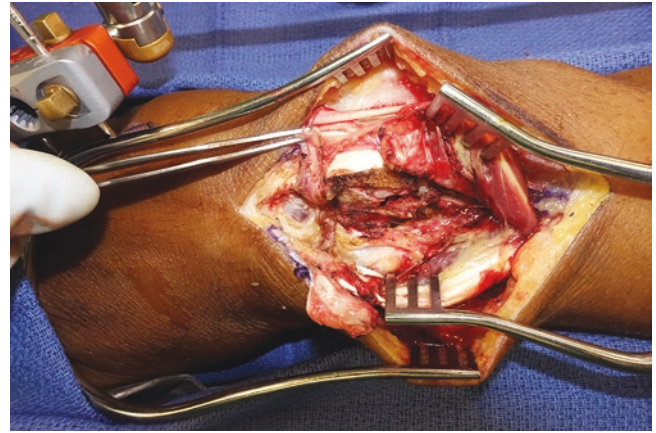


**Fig. 24.134** External fixation with one connecting rod in place and used for intraoperative distraction; dorsal approach outlined

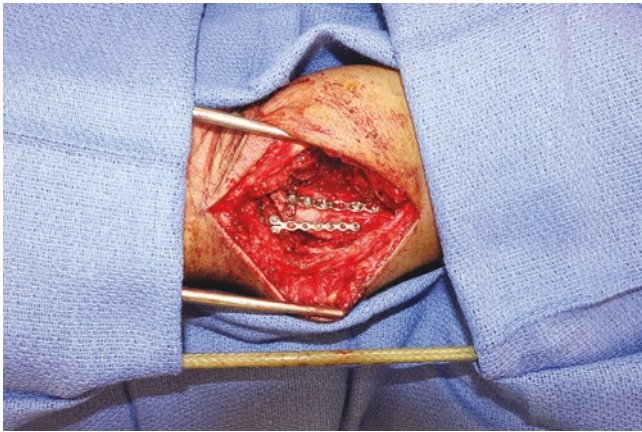




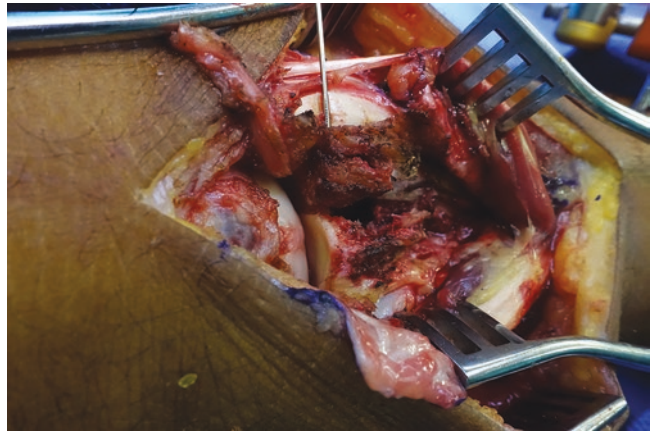
**Fig. 24.135** Flaps outlined on extensor retinaculum midline transverse limb (*arrow*) at level of radiocarpal joint determined by palpation of ulnar head



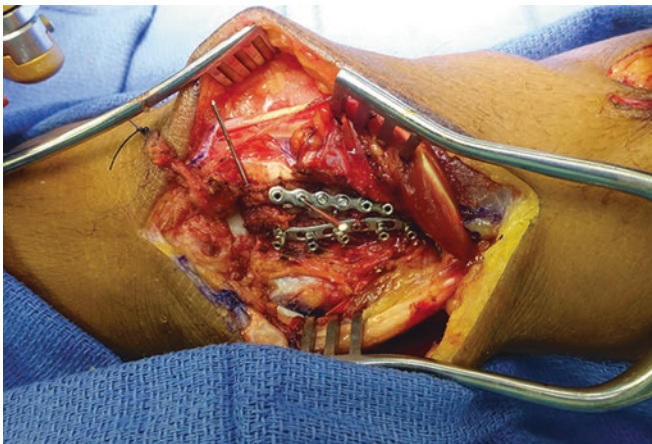
**Fig. 24.136** Synovial reflection in pick-ups



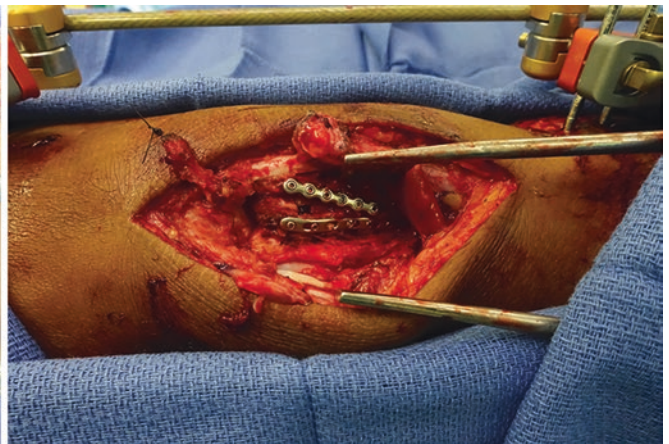
**Fig. 24.137** Anterior fixation positioned first after dorsal exposure



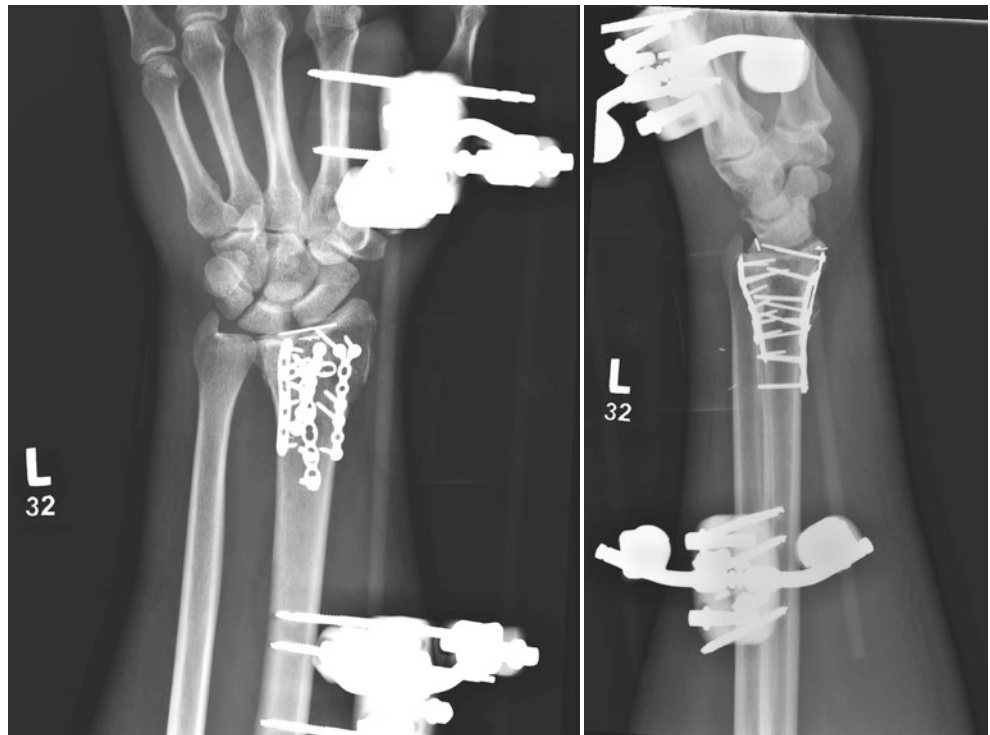
**Fig. 24.138** Joint alignment attained; provisional fixation and defect for bone graft



**Fig. 24.139** Dorsal fixation with 1.5-mm mini locking plates



**Fig. 24.140** Intraoperative radiographs following external and internal fixation



**Fig. 24.141** Follow-up radiographs. Notice wrist extension position to improve finger function



**Fig. 24.142** Radiographs following external fixator removal

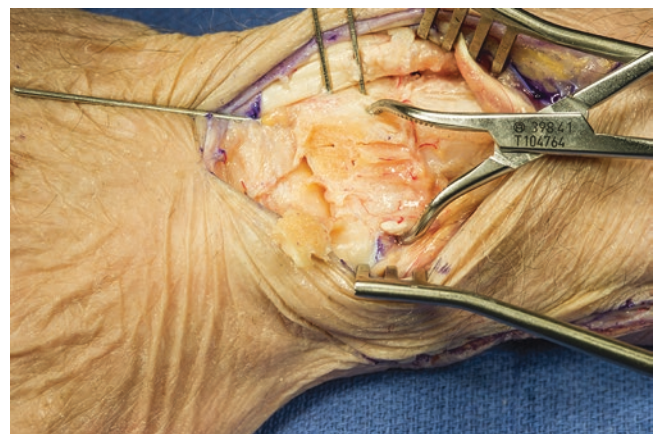


Mini-fragment plates (either 1.5-mm, 2.0-mm, or 2.4-mm locking mini-fragment plates) are utilized for the dorsal fixation. Regardless of the plate selected, securing the fourth-compartment, Lister's tubercle fragment is very important,

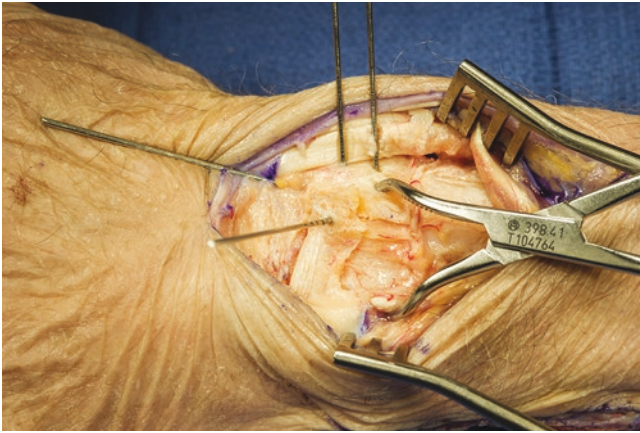
along with joint realignment, in recreating the proper anterior-posterior dimension, which contains the carpus and decreases shearing [29]. Joints don't like shearing (Figs. 24.143, 24.144, 24.145, and 24.146).



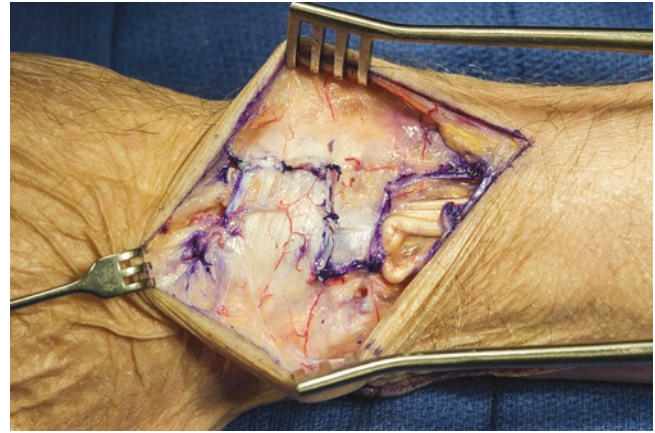
**Fig. 24.143** Intra-articular fracture created along with the dorsoulnar fragment with the dorsal radiotriquetral ligament attached



**Fig. 24.144** Provisional reduction with tenaculums and K-wires



**Fig. 24.145** Dorsal ulnar fragment or Lister's tubercle fragment reduced, followed by dorsal plating (1.5 mm, 2.0 mm, or 2.4 mm, depending on fragment size)



**Fig. 24.146** Retinacular closure, which clinically is usually left with some transverse closure, but not side-to-side

## 24.4 Fractures of the Distal Ulna

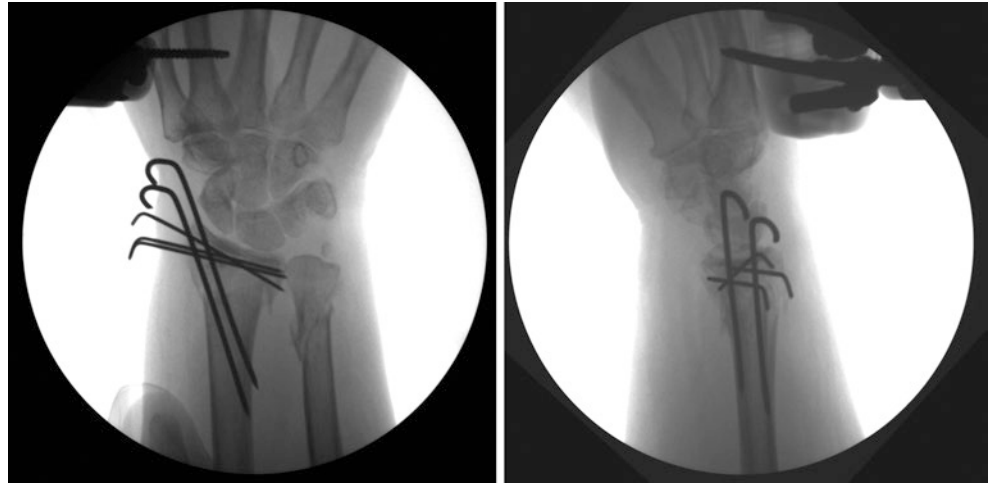
A number of patients will have fractures of the distal ulnar neck, head, and styloid. My recommendation is to leave them alone. The head will settle into a nice ulnar variance,

and you almost can't stop the distal ulna from healing. Besides, the bone quality and comminution makes fixation a less-than-rewarding experience (Figs. 24.147, 24.148, 24.149, 24.150, 24.151, and 24.152).



**Fig. 24.147** Injury radiographs of intra-articular right distal radius and distal ulna fracture

**Fig. 24.148** Fixation radiographs of distal radius with nonoperative treatment of ulna



**Fig. 24.149** Radiographs on discharge with healed distal ulna

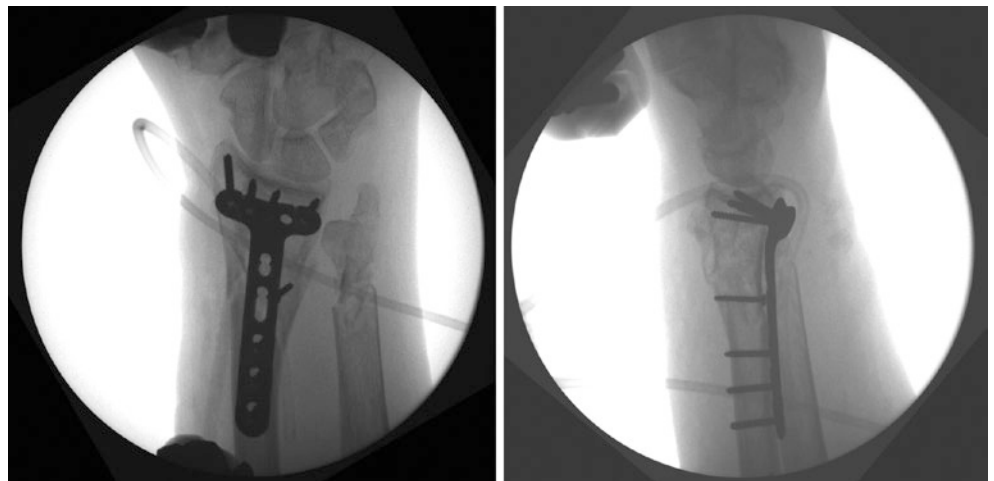




**Fig. 24.150** Injury radiographs of left distal radius and ulna fractures



**Fig. 24.151** Radiographs following debridement and radius fixation without ulna fixation

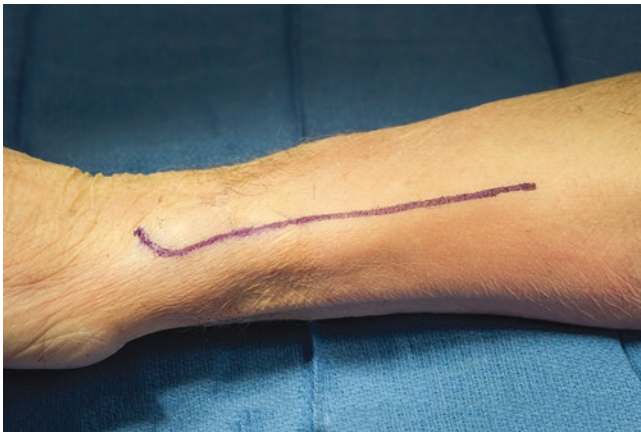


**Fig. 24.152** Radiographs at time of discharge with healed distal ulna

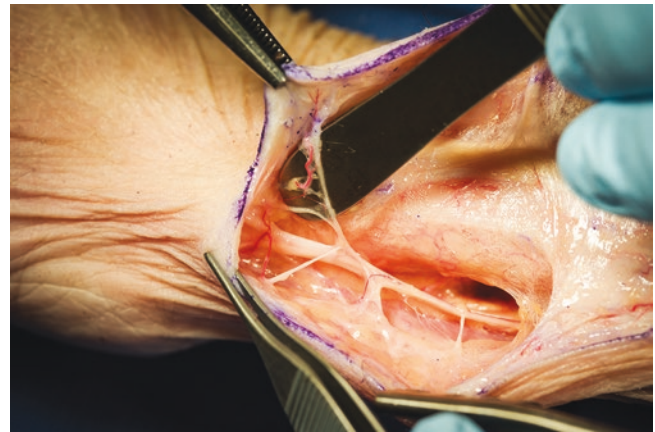


If ORIF is undertaken, the distal extension of the ulnar shaft approach, with a curve over the head, is used, or an extension of the traumatic wound (Figs. 24.153, 24.154,

24.155, 24.156, 24.157, 24.158, 24.159, 24.160, 24.161, 24.162, 24.163, 24.164, 24.165, 24.166, 24.167, 24.168, and 24.169).

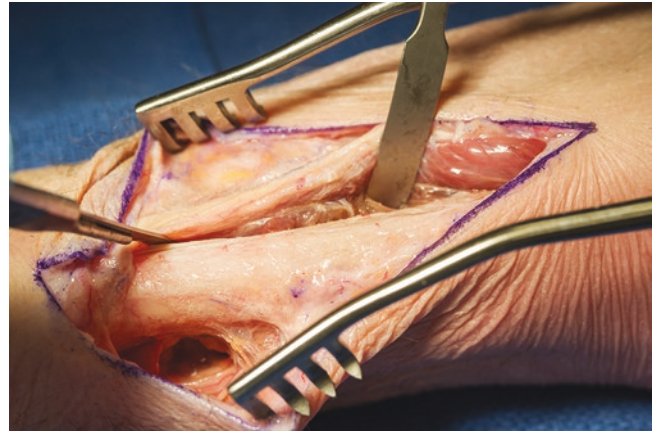


**Fig. 24.153** Incision for distal ulna or ulnar styloid if fixation is required

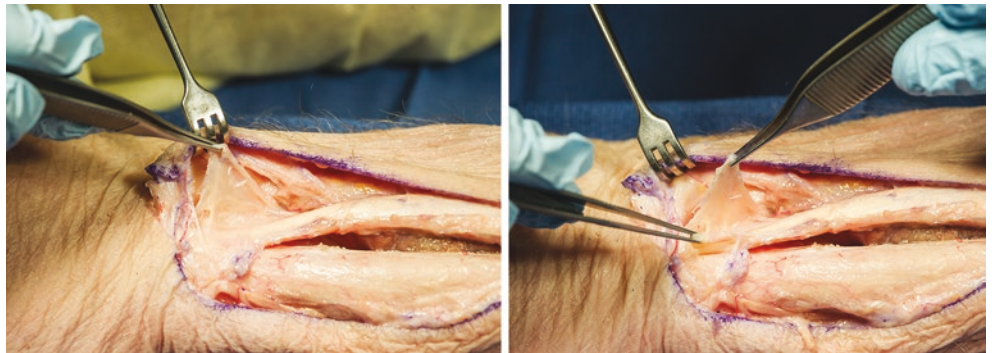


**Fig. 24.154** Dorsal sensory branch of the ulnar nerve, with pickups lifting the transverse branch crossing over ulnar head

**Fig. 24.155** Sub-extensor carpi ulnaris plane developed for plating



**Fig. 24.156** Extensor retinaculum incised and reflected, exposing retinaculum over extensor carpi ulnaris groove in distal ulna



**Fig. 24.157** Oblique view of the two retinacula over the extensor carpi ulnaris





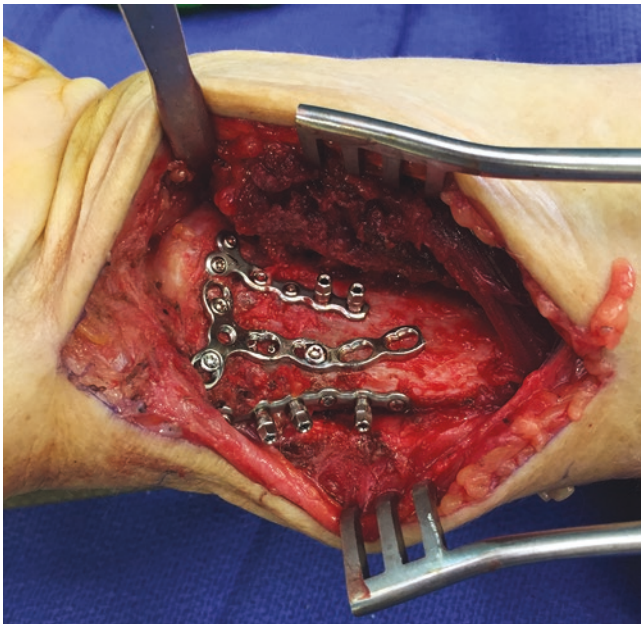
**Fig. 24.158** Injury radiographs of open left distal radius fracture with ulnar styloid fracture



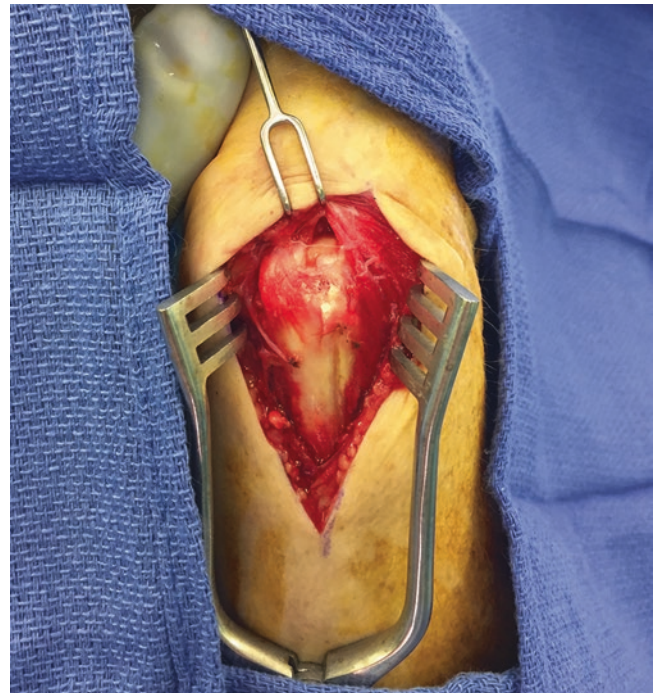
**Fig. 24.159** Traction radiographs revealing rotated anterior fragment



**Fig. 24.160** Incision incorporating open wound

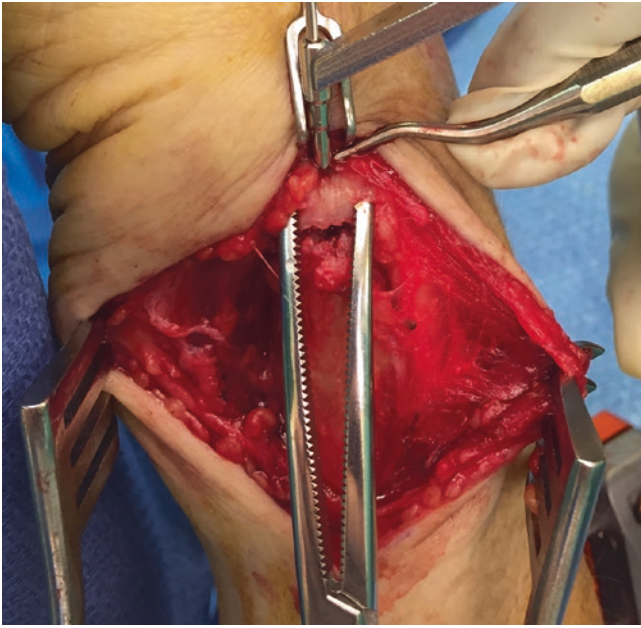


**Fig. 24.161** ORIF of distal radius fracture via anterior approach

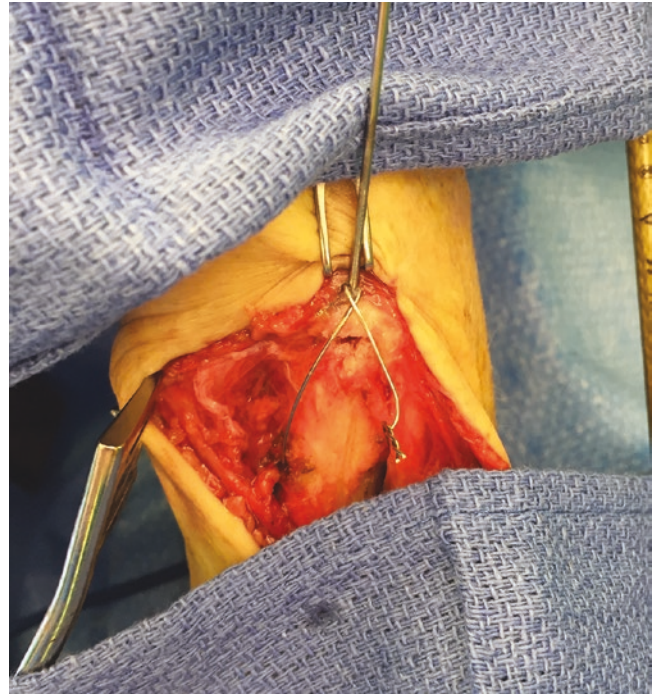


**Fig. 24.162** Approach to distal ulna with transverse hole in distal ulna for tension band wire

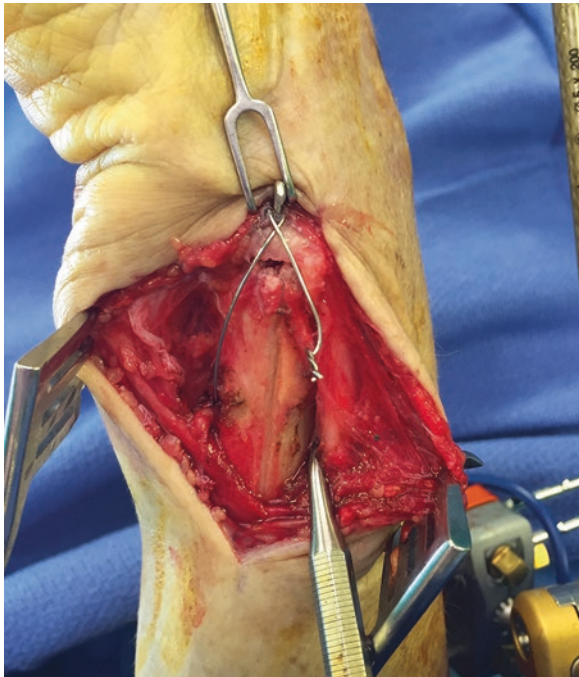




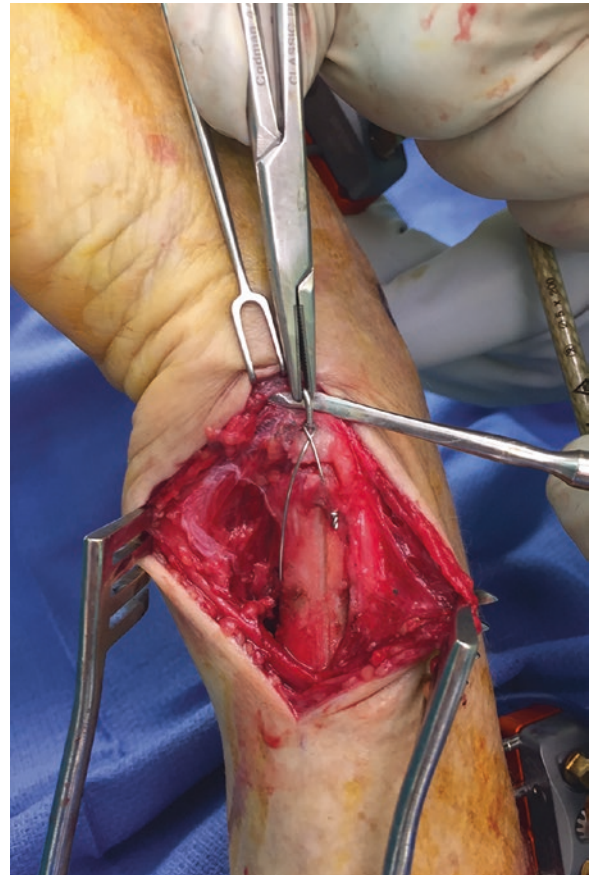
**Fig. 24.163** Reduction of ulnar styloid with curved Kocher



**Fig. 24.164** Reduction and fixation prior to turning down wires



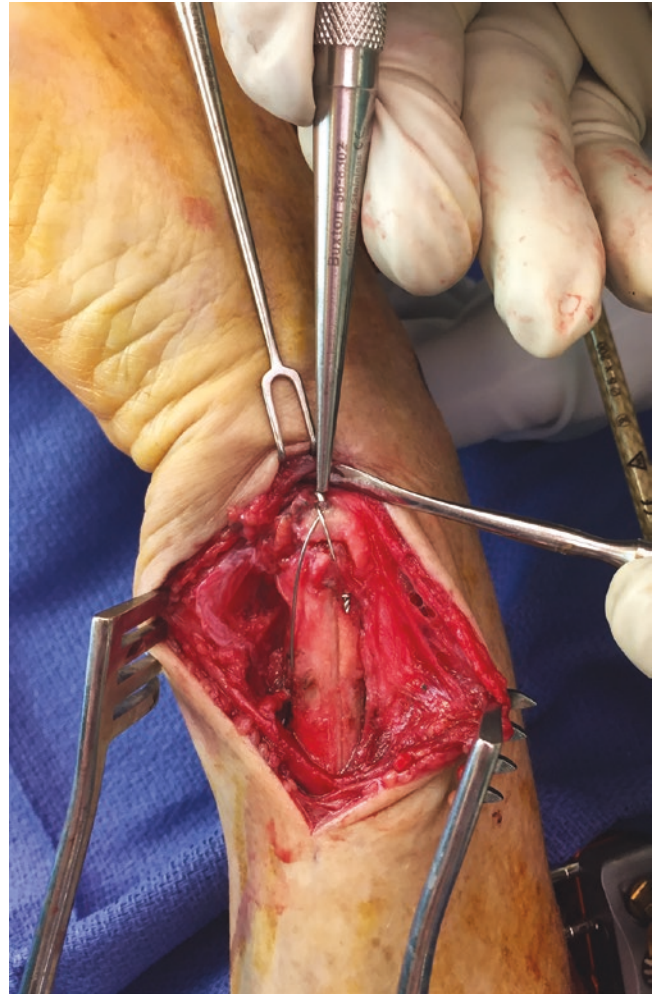
**Fig. 24.165** K-wire bent and cut but not rotated



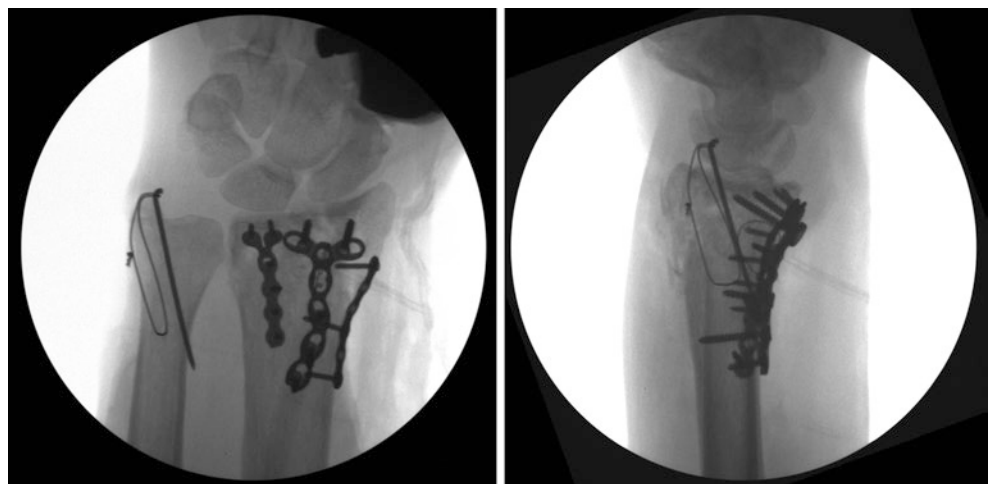
**Fig. 24.166** K-wire turned after tension band wires are twisted down, in case a tension band wire breaks and needs to be replaced



**Fig. 24.167** K-wire being seated



**Fig. 24.168** Intraoperative radiographs following ORIF of the radius via an anterior approach only and ulnar styloid fixation



**Fig. 24.169** Radiographs at time of discharge



## 24.5 Closure and Postoperative Care

Once fixation is completed, closure is performed, usually beginning with the closure of the synovial reflection between the dorsal radiotriquetral and scaphotriquetral ligaments. The retinaculum is closed; usually the limbs are not completely approximated. The anterior closure begins with the pronator quadratus re-approximated to the brachioradialis with 3-0 PDS®. The tourniquet is then deflated and hemostasis and bleeding of the radial artery are checked, followed by closure with Vicryl® and a running subcuticular 3-0 Prolene® suture. Sometimes swelling precludes complete closure of either incision; in this instance, I generally don't use a vacuum-assisted closure (V.A.C.)® acutely. I use Xeroform® daily dressing changes and wait 3 to 5 days, then returning to the operating room for closure or split-thickness skin grafting.

The drain in the anterior approach exits radial distal, not central through the palmar cutaneous nerve. The drains exit distally. (As if trying to get water out of a well, you put the hose at the bottom.) After completion of closures, the patient is placed in an arm elevator and therapy begins the next day.

Therapy of the hand includes range of motion of the shoulder and elbow, as hand patients tend to keep their arms adducted and internally rotated. Control edema with finger range of motion, retrograde massage, and elevation. Activities of daily living (ADLs) are encouraged if the patient's medical condition permits. External fixators remain in place for about 4–6 weeks, depending on the bone quality, and are removed in the clinic. Range of motion is begun 2 weeks after the fixator is removed; strengthening and weight-bearing are usually allowed 8 weeks postoperatively.

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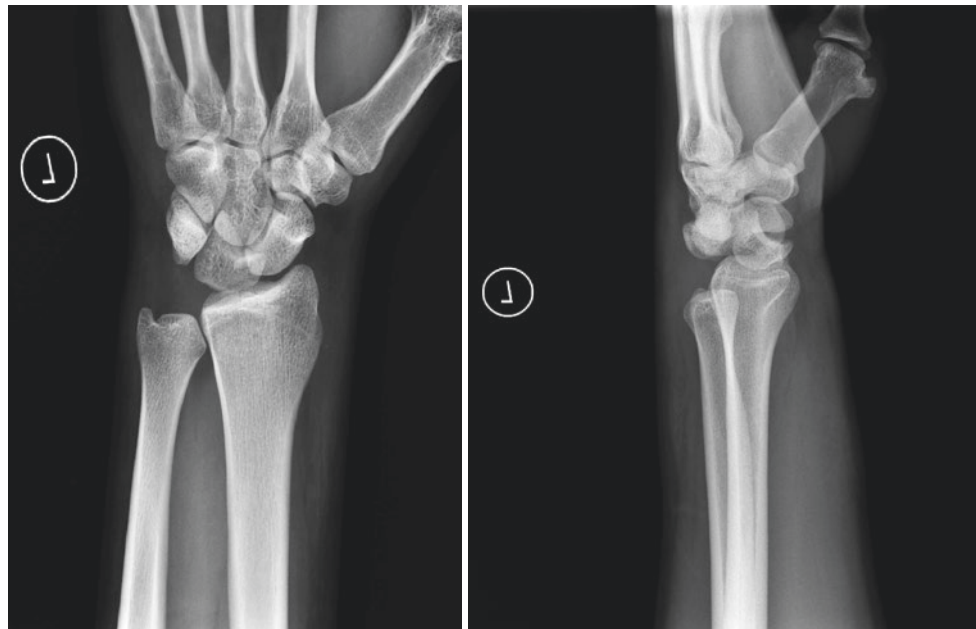


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## 25.1 Definitions and Frequency

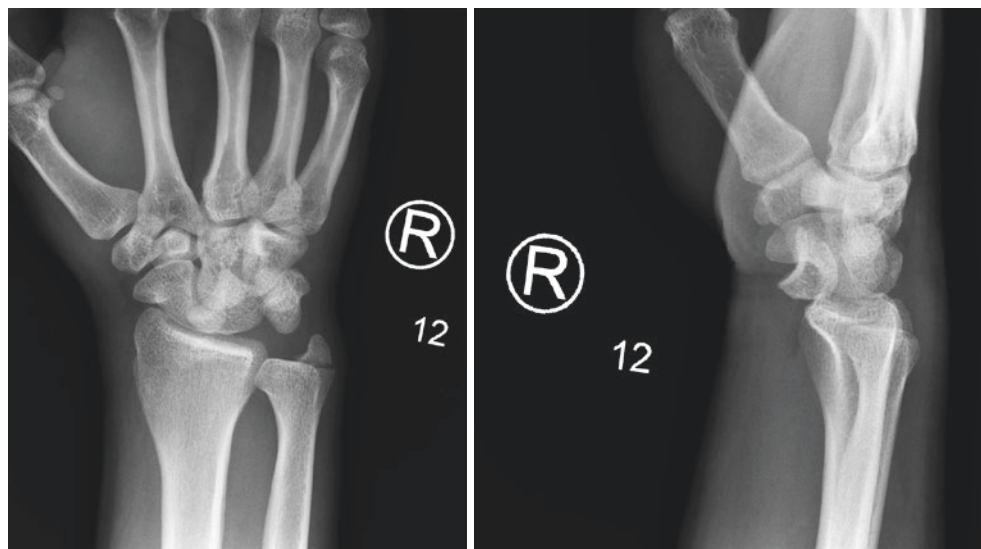
Perilunate injuries—whether purely ligamentous perilunate dislocations, transscaphoid perilunate dislocations, or variants—are usually associated with less than desirable or normal results [1–6]. It is known that open injuries and treatment delay are particularly problematic and are associated with poor results [2]. Regardless of the timing of treatment or the method of fixation, however, arthritic development does not preclude satisfactory clinical results.

Of perilunate dislocations, approximately 95% are said to involve the dorsal perilunate or transscaphoid perilunate, with the transscaphoid type being most prevalent [2]. The experience at Shock Trauma is slightly different: About a third are perilunate, a third are transscaphoid perilunate, and a third are variants that include transscaphoid transcapitate transtriquetral and other variations (Figs. 25.1, 25.2, 25.3, and 25.4).



**Fig. 25.1** Radiographs of left wrist dorsal perilunate dislocation with triangular lunate on posteroanterior (PA) view and dorsal carpus with lunate tipped but still in lunate fossa on lateral view

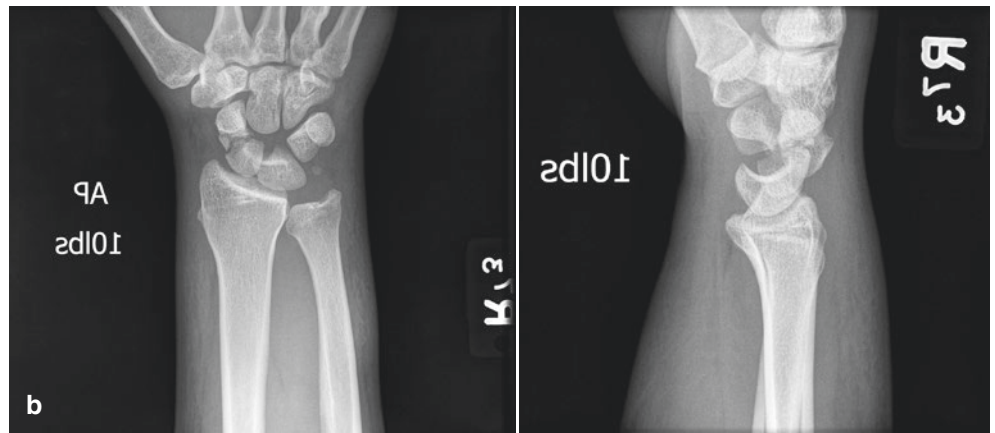
**Fig. 25.2** Radiographs of right wrist perilunate dislocation with lunate rotated out of fossa



**Fig. 25.3** (a) Injury radiographs of right wrist transscaphoid perilunate dislocation. (b) Traction radiographs demonstrating comminuted scaphoid and dissociation of lunate and triquetrum



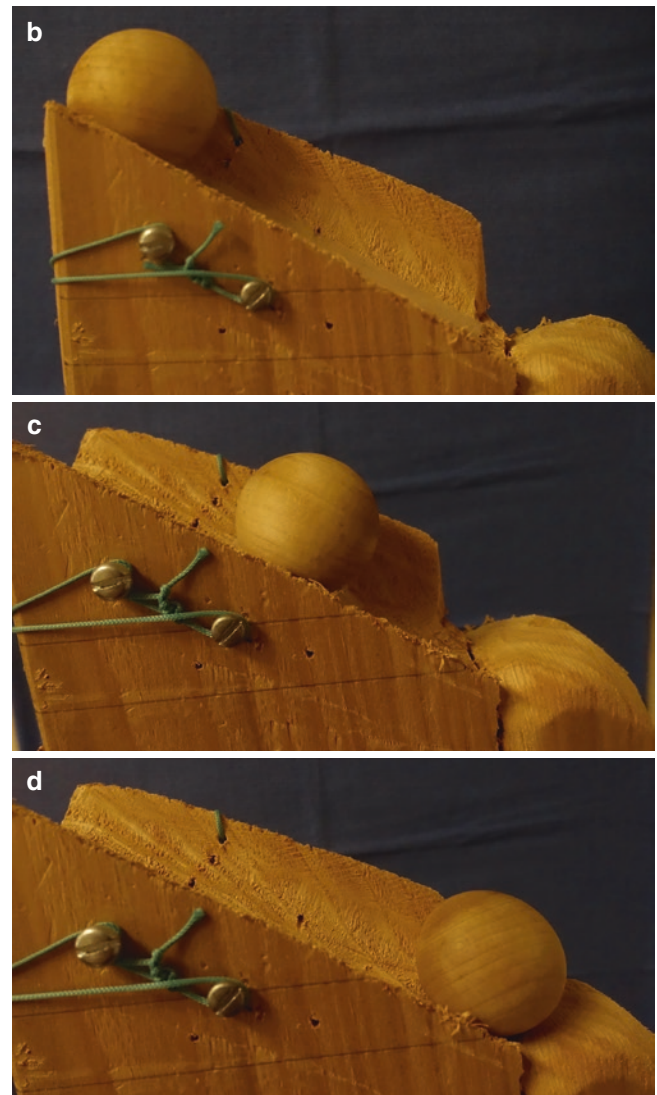
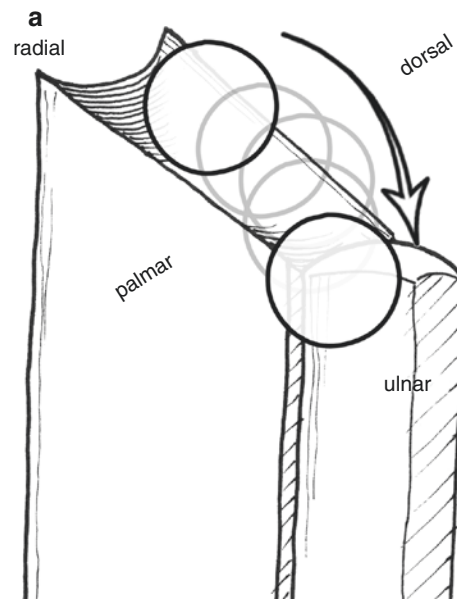


**Fig. 25.3** (continued)**Fig. 25.4** (a) Injury radiographs of left wrist transscaphoid transcapitate transtriquetral fracture dislocation. (b) Traction radiographs of left wrist

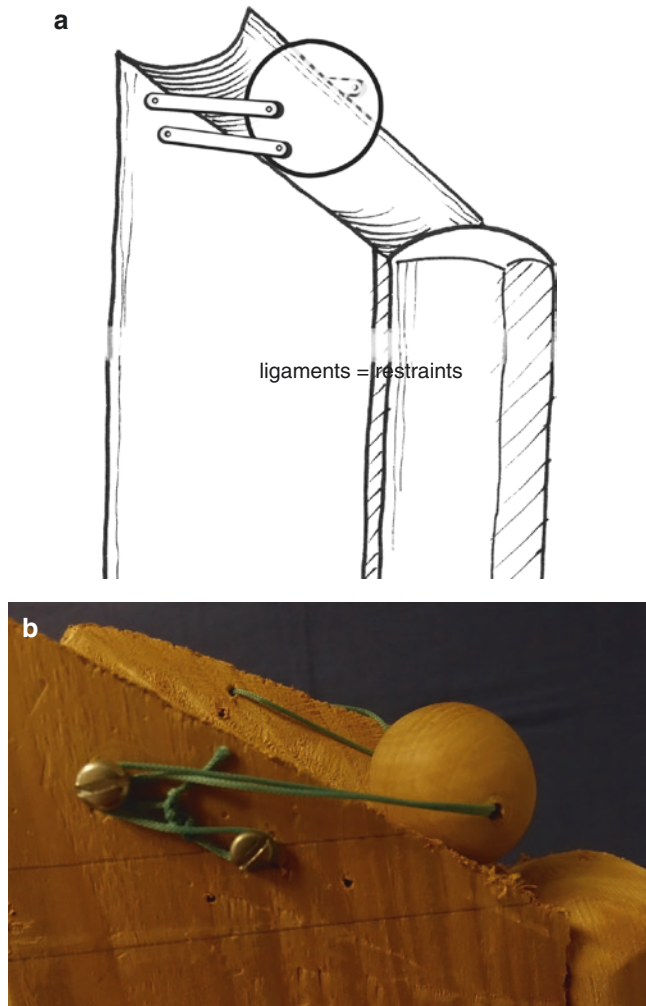
Perilunate injuries are discussed here in three sections: anatomy, mechanism of injury, and treatment options.

## 25.2 Anatomy

The complexity of the wrist and its ligamentous constraints tends to be overwhelming, making the understanding of the subsequent disorders that much more difficult. In an effort to simplify the mechanics of the wrist, we begin with the radiocarpal joint. The distal radius can be simplified to basically a slanted structure, such that the high point is dorsal distal radius to palmar ulnar. You can see that any structures placed on this platform naturally tend to roll or slide palmarly and ulnarly (Fig. 25.5). If we were attempting to resist this tendency for displacement purely from gravity, we would place restraining structures (Fig. 25.6).

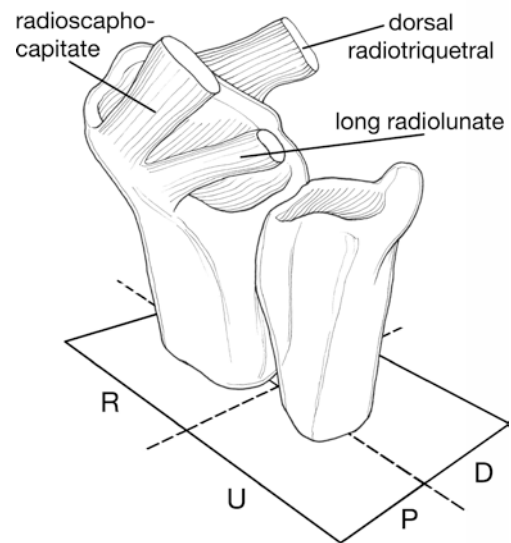


**Fig. 25.5** (a–d) Unconstrained ball rolling down an inclination



**Fig. 25.6** (a, b) Restrained ball, preventing further propagation

Thus, the major ligaments are positioned and oriented to hold the carpus from sliding off. The most important are the palmar extrinsic ligaments, the radioscaphocapitate ligament, and the long and short radiolunate ligaments (Fig. 25.7). (Note that the radioscapholunate ligament of Testut is actually a neurovascular mesentery with no structural importance—so don't blurt it out when I ask about the importance of various ligaments.) Dorsally, the dorsal radiotriquetral ligament is assigned the restraining job.



**Fig. 25.7** Extrinsic radiocarpal ligaments



Moving on distally to the carpus, let's look at the shape and some dynamics of the lunate, scaphoid, and triquetrum. The keystone of the carpus is the lunate. The classic teaching is that the lunate is wedge-shaped, being wider anteriorly than dorsally. Early reports and studies, using radiographs to define lunate morphology, cited this shape [7]. Recent CT scan analysis has challenged this dictum, however, so we are going to consider the lunate as a curved wedge [8–10]. As such, if the lunate is placed flat and pressure is applied from distal to proximal, the lunate will rotate into an extended position with the distal surface rotating to face dorsally. The scaphoid rotates into flexion when subjected to an axial load, commensurate with its somewhat peanut-shaped overall geometry. The triquetrum is a little more complex, and with due respect to the work done by Moritomo *et al.* [11] and McLean *et al.* [12], the triquetrum extends when the joint goes into ulnar deviation, effectively when experiencing a longitudinal force. Therefore, we have the scaphoid, which wants to flex, and the triquetrum, which wants to extend; the lunate is stuck in the middle, with some potential for extension.

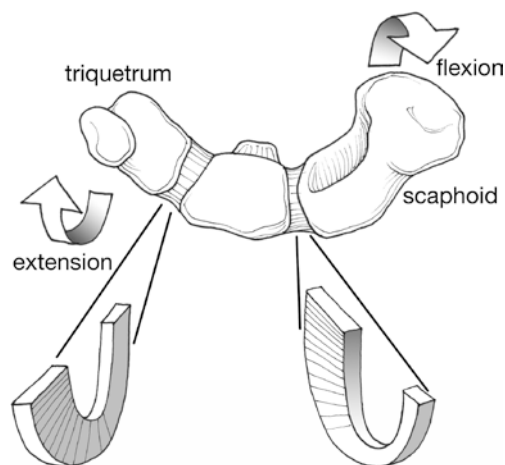
So why doesn't the proximal row fall into collapse and disarray? The answer is the ligaments and their anchoring site, the lunate. The tendency for the triquetrum to go into extension and the scaphoid into flexion is balanced by the lunate as if it had two arms holding the scaphoid and the triquetrum from rotating (Fig. 25.8).



**Fig. 25.8** Lunate holding scaphoid and triquetrum in place

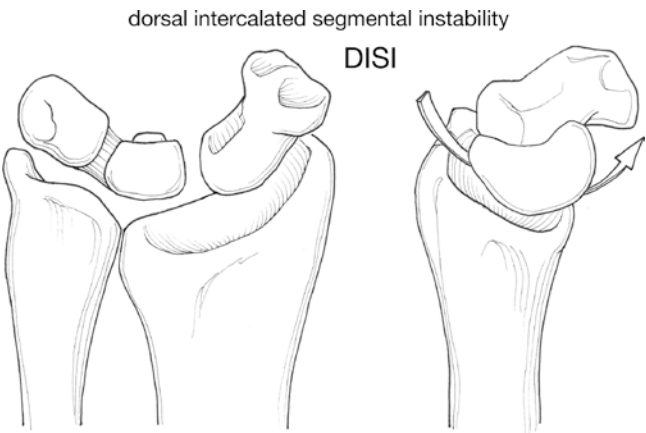
The forces are balanced through the ligamentous constraints between the scaphoid and lunate and the lunate and triquetrum. I will disparagingly comment that the lunate is dumb and incapable of independent thought—it follows whomever it is holding onto; that is, whoever is still ligamentously attached.

The rotation point of the scaphoid/lunate relationship is dorsal, in the stout portion of the scapholunate interosseous ligament [13, 14]. The ligament has three zones, with the dorsal being the strongest and thickest. Commensurate with this thought process is that the palmar aspect of the lunotriquetral ligament is thicker and stronger, again reflecting the axis of rotation (Fig. 25.9).



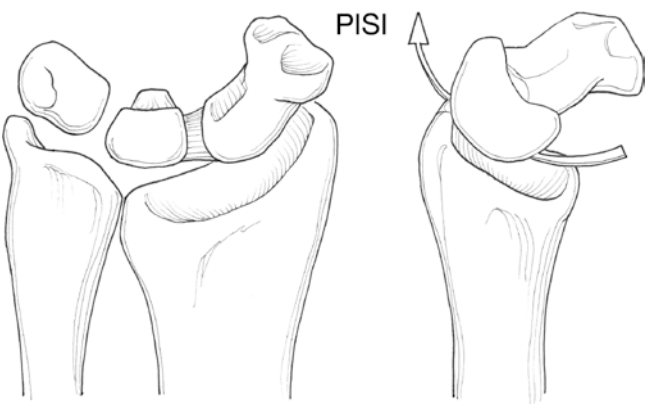
**Fig. 25.9** Intrinsic ligaments balancing the proximal carpal row

The next step is to consider sectioning either of these ligaments and consider what happens when one side is unrestrained. If the scapholunate interosseous ligament is divided and we apply longitudinal pressure, the scaphoid acts untethered and rotates into flexion. The triquetrum goes into extension, taking the lunate with it. We therefore see an increase in the scapholunate angle because of the flexed position of the scaphoid and the extended position of the triquetrum and lunate (Fig. 25.10).



**Fig. 25.10** Dorsal intercalated segmental instability

Conversely, if the lunotriquetral ligament is divided, the scaphoid and its partner the lunate rotate down into flexion, while the triquetrum again goes into extension. Thus we see a decrease in the scapholunate angle (Fig. 25.11).



**Fig. 25.11** Palmar intercalated segmental instability

This is a simplification; there must be associated ligamentous attenuation to really attain the dorsal intercalated segmental instability (DISI) and palmar intercalated segmental instability (PISI) position. Attenuation of the radioscaphocapitate (RSC), extrinsic, and scaphotrapezial–trapezoidal (STT) ligaments is needed for the DISI position to be obtained, and attenuation of the dorsal radiotriquetral and ulnocarpal ligaments is required for the PISI position to occur.

### 25.3 Mechanism of Injury

With the understanding of the static balancing act of the ligaments and the geometry of the distal radius and carpus, we can now understand the mechanism of injury, with the sequence of ligamentous injuries (Table 25.1). The established mechanism of a fall on the extended wrist results in a forced ulnar deviation of the wrist in extended position with intercarpal supination [15, 16]. The sequence of ligamentous injuries actually begins with what is called a Stage I scenario, with attenuation of the radioscaphocapitate ligament. The subsequent failure of the scapholunate interosseous ligament results in widening of the scapholunate joint or scapholunate dissociation. This is seen radiographically as a widening of the scapholunate interval. The second stage is disruption of the radioscaphocapitate ligament and the radial collateral ligaments, resulting in Stage II perilunate injury with capitate dislocation.

With further ulnar deviation of the wrist in extension, the lunotriquetral joint is disrupted, with tearing of the lunotriquetral ligament and ulnocarpal ligaments in Stage III, with associated lunotriquetral dissociation. Finally, in Stage IV, the dorsal radiotriquetral ligament complex is disrupted. Stage IV can be confusing, as the lunate will sometimes remain in the lunate fossa in a Stage IV injury, rather than being dislocated. Stage IV is thus divided into a stage 1 (lunate remains in the fossa) and stage 2 (dislocation). This too can be confusing, as some individuals talk about a lunate dislocation as if it is not part of the perilunate injury.

**Table 25.1** Stages of perilunate injury and instability

Stage	Ligament
I—Scapholunate joint	Scapholunate
II—Capitolunate joint	Radioscaphocapitate
III—Lunotriquetral joint	Lunotriquetral
IV—Radiolunate joint	Dorsal radiotriquetral

Another misconception is that there can be either a bony injury or a ligamentous injury, but not both. Specifically, it is said that transscaphoid fracture-dislocations “should not” be associated with an injury to the scapholunate interosseous ligament, but this has been disproved by Mayfield and Johnson [15–19].

There can be a number of variations, sweeping from radial to ulnar in arcs described as *inferior*, *lesser*, and *greater*. The inferior arc is the radiocarpal joint. The lesser arc goes through the scapholunate, capitolunate, and triquetral joints. The greater arc refers to the maximal extreme of the transradial styloid, transscaphoid, transcapitate, and transtriquetral fracture dislocations.

## 25.4 Treatment Options

When this injury complex is encountered, treatment options must be considered. The spectrum is quite extensive, extending from closed treatment with no surgical intervention to acute salvage procedures that include proximal row carpectomy and intercarpal fusions. Closed treatment has been found to be occasionally successful, but Adkison and Chapman [20] documented a failure rate of about 60%. Other options include arthroscopically assisted reduction and fixation.

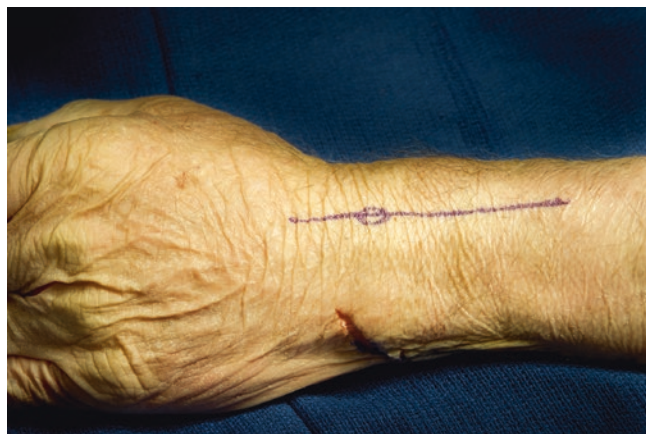
### 25.4.1 Transarticular Fixation

The most common approach is open reduction with some form of stabilization. Depending on the time frame for entry

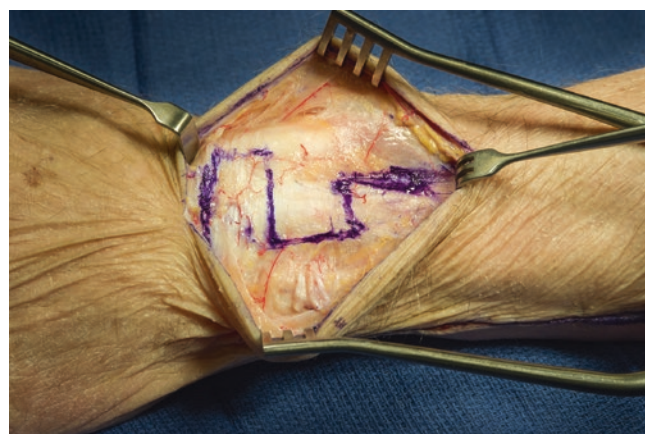
into the operating room, I will occasionally leave the complex dislocated, as doing so can facilitate the subsequent fixation placement utilizing the window from the defect of the anteriorly dislocated lunate.

I tend to use a dorsal approach, going anterior if median nerve symptoms are present and do not abate with closed reduction, or if an anterior approach is required for access to the unreducible dislocated carpus, usually the lunate or the lunate and the proximal pole of the scaphoid. This approach also allows access to the carpal fragments, particularly those off of the lunate, if fixation is deemed necessary. When I have gone anterior, I am taken that after even a provisional reduction, the anterior ligaments are nicely approximated and I wonder about the utility of putting in a stitch. A few weeks of postoperative immobilization should allow adequate early healing.

The patient is in the supine position with a nonsterile tourniquet applied. The set-up, prepping, and draping are presented in Chap. 21. The dorsal approach utilized is similar to that for dorsal open reduction and internal fixation (ORIF) of the distal radius. The incision is from the carpometacarpal joint, crossing between the index and long metacarpal bases, as this incision facilitates orientation in a longitudinal fashion, particularly if one cannot palpate Lister’s tubercle. A midline dorsal incision is carried to the metadiaphyseal region of the radius (Fig. 25.12). The incision is carried out under tourniquet control. The extensor retinaculum is visualized, and double rectangular flaps are outlined (Fig. 25.13).



**Fig. 25.12** Dorsal incision midline over Lister’s tubercle



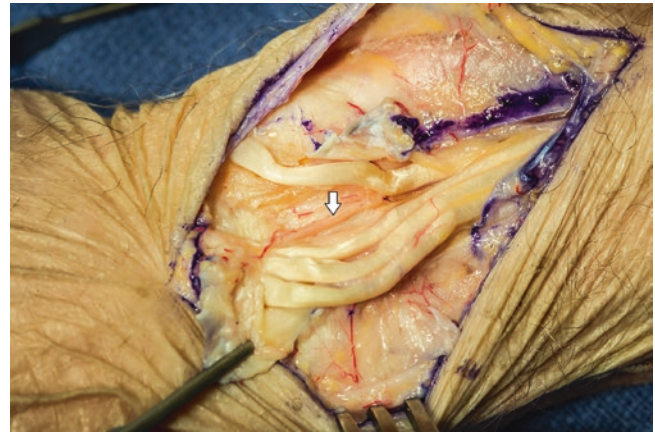
**Fig. 25.13** Double rectangular flaps outlined on extensor retinaculum



The transverse limb is at the mid portion of the retinaculum commensurate with the radiocarpal joint. The ulnar limb is between the fourth and fifth compartment, and the radial limb distally is between the extensor pollicis longus (EPL) and the wrist extensors. The flaps are elevated, and with peri-

unate dislocations, I try not to move the EPL out of the third compartment (Fig. 25.14). The posterior interosseous nerve (PIN) is usually divided proximally, acknowledging the concern about the potential for proprioception issues relative to the radiocarpal and distal radioulnar joint [21].

**Fig. 25.14** Flaps elevated, extensor pollicis longus mobilized to demonstrate posterior interosseous nerve (*arrow*)

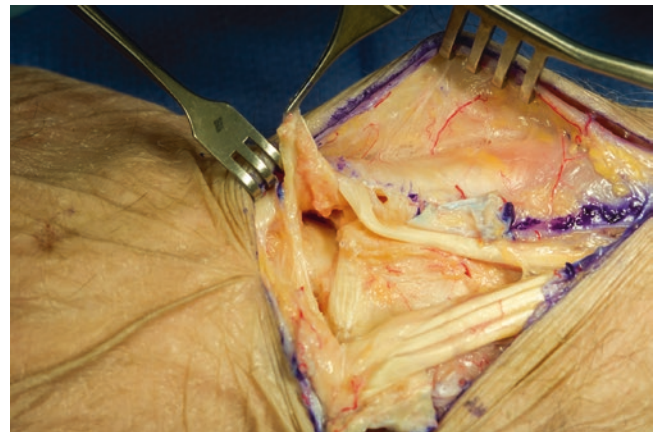


The fourth compartment is mobilized ulnarly with investing tenosynovium. This allows visualization of the dorsal ligaments, the dorsal radiotriquetral and scaphotriquetral (Fig. 25.15). Depending on the zone of injury, the synovial

reflection between these two is taken radially (Fig. 25.16). This allows direct visualization of the defect as a consequence of the anterior lunate dislocation, such that the scaphoid and triquetral lunate facets can be directly visualized.



**Fig. 25.15** Exposure of dorsal radiotriquetral ligament (*arrow*)



**Fig. 25.16** Synovial reflection between the dorsal radiotriquetral and scaphotriquetral ligaments

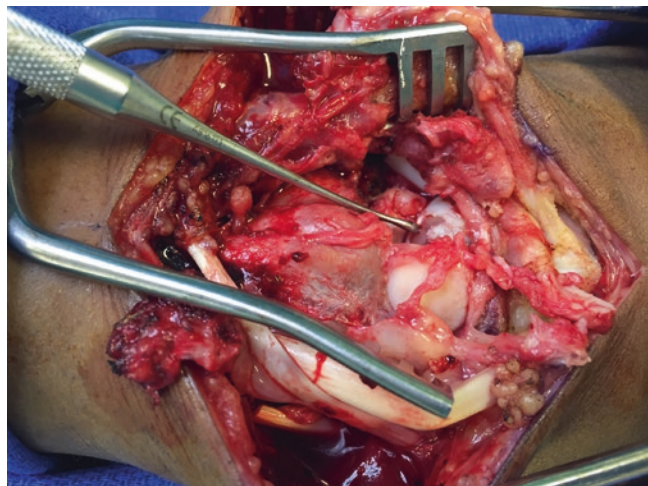
The triquetrum will frequently have a palmar corner avulsion, which I have dubbed the *Mayfield sign*, acknowledging the ulnocarpal complex avulsion as described by Mayfield *et al.* [15, 16]. Recognition of this avulsion fragment is important to provide awareness that what seems on first

glance to be simply a scaphoid fracture may actually be a component of a perilunate injury (Fig. 25.17). Sometimes this fragment can be seen from the dorsal approach, but direct fixation may require an anterior approach.

**Fig. 25.17** (a) Radiographs demonstrating fleck Mayfield sign (*arrow*). Initial review of the film may reflect just radial and ulnar styloid fractures. (b) Radiographs on presentation, revealing a perilunate injury



The head of the capitate should be examined; there is frequently a gouge in the head of the capitate commensurate with the dislocation (Fig. 25.18). If considering a salvage procedure, I do not let this gouge prevent the use of a proximal row carpectomy.



**Fig. 25.18** Kleinert-Kutz elevator pointing to defect in the head of the capitate

The dorsal radiotriquetral ligament is preserved. However, it is commonly attenuated or partially avulsed, and should be repaired during the closure. I use transarticular screws across the scapholunate and lunotriquetral joints; I have gotten away from K-wires, at least in part because of the associated development of septic arthritis from protruding K-wires.

Using a threaded 0.045-in. or 0.0625-in. Steinmann pin as a joystick in the lunate, the scaphoid is mobilized and I pre-drill the scaphoid inside out using a 0.045-in. K-wire. The hole drilled by the threaded pin can also be used for a pilot hole if a suture anchor is used for ligament repair. I then utilize a 1.1-mm guidewire, which is used for the 2.4-mm or 3.0-mm headless screw. The threaded tip guide is placed in reverse fashion to allow the point to be adjacent to the lunate when reduced. I place a second 0.045-in. K-wire slightly palmar to this, with both of these exiting radially. For screw fixation, a second incision will be required radially, and often a third ulnarly.

The guidewire position is slightly dorsally oriented in an effort to simulate the axis of rotation between the scaphoid and lunate. The triquetrum is now delivered, generally using a Freer as a shoehorn or lift. An inside-out 0.045-in. K-wire is placed, followed by a reversely placed guidewire. The guidewire positioning is slightly palmar to correlate with the axis of rotation. With the guidewires and the K-wires positioned, the lunate is reduced. I have found no single maneuver for reduction. Generally, traction, direct pressure on the

lunate, and some degree of flexion/extension at the mid carpal joint is required.

The scapholunate interosseous ligament is frequently avulsed in the lunate, and I will pre-drill with 1.1-mm drill bits through the lunate from dorsoulnar into the scapholunate joint. I then place 26- or 28-gauge interosseous wires in a loop fashion to allow a 3-0 or 4-0 Ethibond® suture to be passed from the scapholunate ligament, which is still attached to the scaphoid.

The reduction is then carried out using the Steinmann pin as a joystick, along with a dental pick to manipulate the scaphoid. The 0.045-in. K-wire in the scaphoid is advanced, followed by the threaded-tip guidewire. Many C-arm shots may be required before the desired alignment and reduction are obtained. Occasionally a tenaculum must be incorporated to reduce the scapholunate gap. Once acceptably positioned, the lunotriquetral reduction is carried out. The guidewire is advanced while the position is checked on the image. When the alignment is acceptable, an incision is made radially over the guidewire. Depth and length are established, and the soft tissue protector is placed under direct visualization.

Over-drilling is carried out, followed by insertion of a headless screw. Once the length has been measured, it is helpful to advance the guidewire, then grasp with a hemostat, as guidewires occasionally back out or shear off, and the hemostat will facilitate retrieval if it is inadvertently broken off.

Once the scapholunate screw is inserted, the lunotriquetral screw is inserted next, after the ulnar incision is performed. More commonly, the seating of the guide and depth gauge is performed under image control because of the difficulty of direct triquetral visualization. The guidewire is advanced into the radiocarpal joint so it can be captured with a hemostat to prevent its backing out. The over-drilling is performed and the lunotriquetral (LT) screw is inserted.

The scapholunate (SL) derotation K-wire is bent and cut; the wire will be removed 6–8 weeks after surgery. Repair of the scapholunate ligament is now performed. The 3-0 or 4-0 Ethibond® is placed in a locking fashion. Be very careful; the ligament tends to shred, so you may get only one shot at doing this. (Take that as a hint to whoever is holding the needle driver.) The free ends of the suture are then placed in the wire loops and delivered dorsally over the lunate. This step requires you to have paid attention to the drill holes made in the lunate, making sure you were not too deep in the scapholunate joint; the result would be pinching the wires during reduction of the joint. A suture anchor can also be used, but it can be more difficult because of the traffic in the lunate from the screws and K-wires. The scapholunate interosseous ligament suture is tied. The synovial reflection is now sutured with 3-0 or 4-0 PDS®, incorporating the lunotriquetral ligamentous complex.



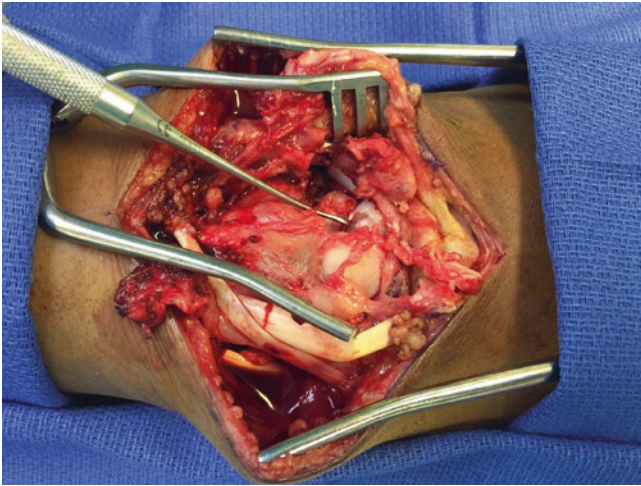
The dorsal radiotriquetral ligament repair is carried out through transosseous holes drilled radial to ulnar to exit along the base of Lister's tubercle and the dorsal distal radius rim. Suture anchors may also be used. The retinacular reapproximation is performed with 3-0 PDS®, and skin closure is with Vicryl® and Prolene® over a medium Hemovac® drain (Figs. 25.19, 25.20, 25.21, 25.22, 25.23, 25.24, 25.25, 25.26, 25.27, 25.28, 25.29, 25.30, 25.31, 25.32, 25.33, 25.34, 25.35, 25.36, and 25.37).

After the surgery, I utilize a sugar-tong splint with the thumb incorporated, then transition to a short arm thumb spica at the first clinic visit. A short arm thumb spica cast will be worn for about 6 weeks, followed by an orthotic for about 2 weeks, after which the derotation K-wire is removed.

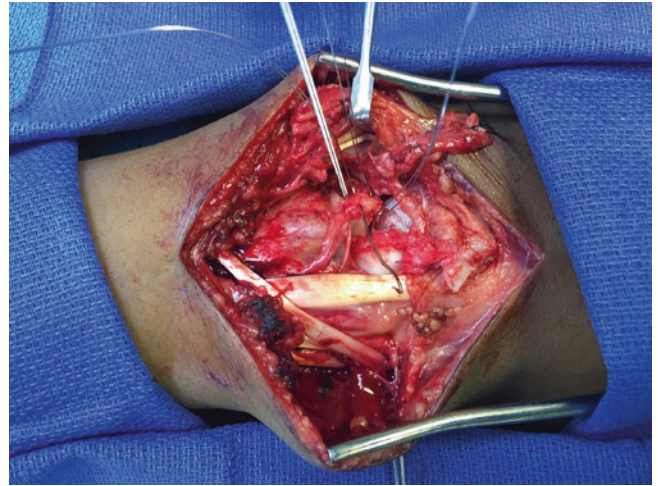
**Fig. 25.19** Retinacular repair



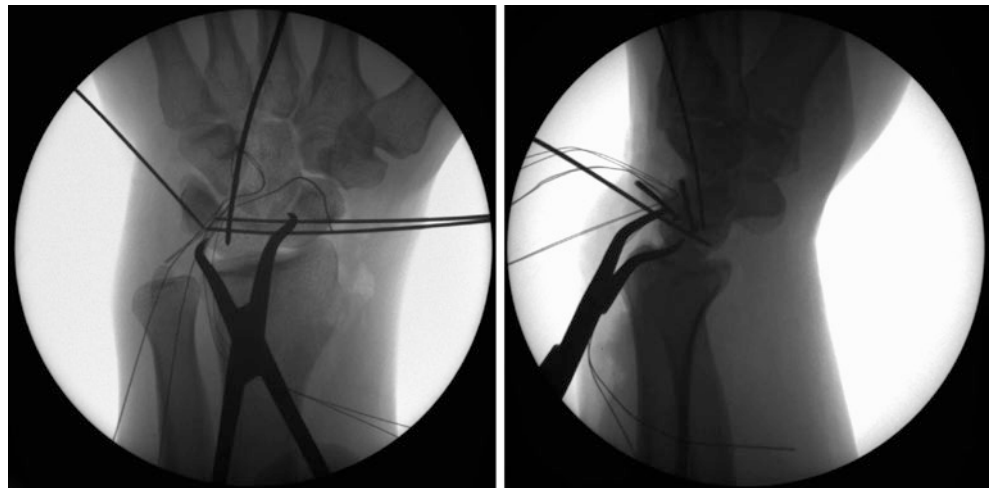
**Fig. 25.20** Injury radiographs of left dorsal perilunate dislocation



**Fig. 25.21** Dorsal approach with dorsal radiotriquetral ligament avulsed off the radius and a defect in the capitate head



**Fig. 25.22** Wires passed through the lunate for suture passage for repair of scapholunate interosseous ligament, with a joystick in the lunate



**Fig. 25.23** Intraoperative radiographs in preparation for transarticular fixation, with joystick and wires for suture passage

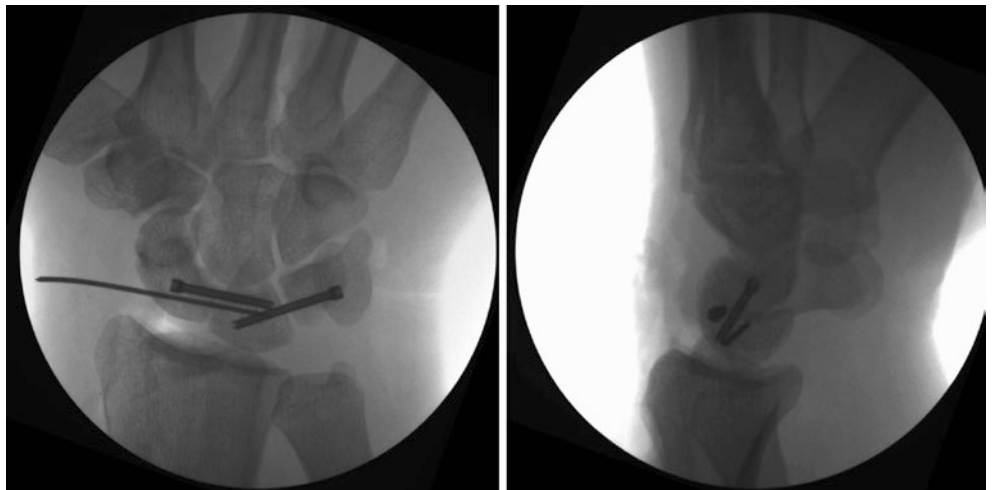
**Fig. 25.24** Scapholunate screw insertion



**Fig. 25.25** Lunotriquetral screw insertion with a hemostat holding the guidewire to prevent migration

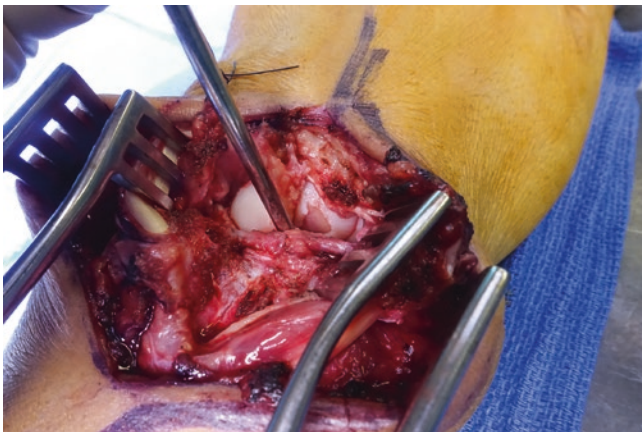


**Fig. 25.26** Final intraoperative radiographs

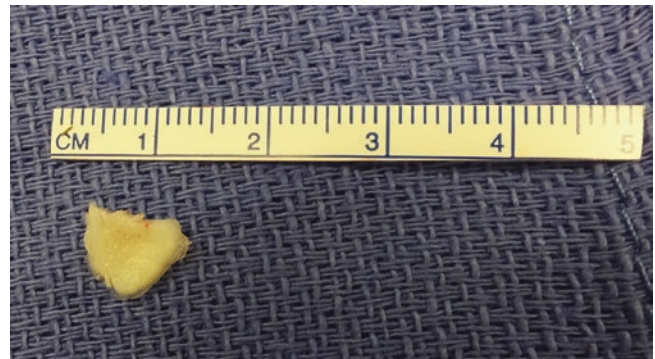




**Fig. 25.27** Radiographs of right dorsal perilunate dislocation



**Fig. 25.28** Dorsal approach demonstrating capitate head defect

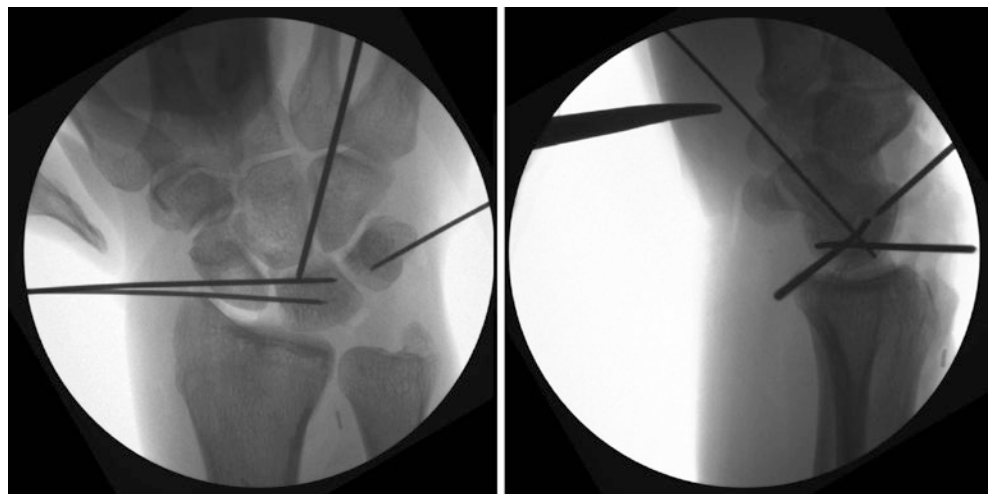


**Fig. 25.29** Fragment of capitate articular cartilage retrieved during approach

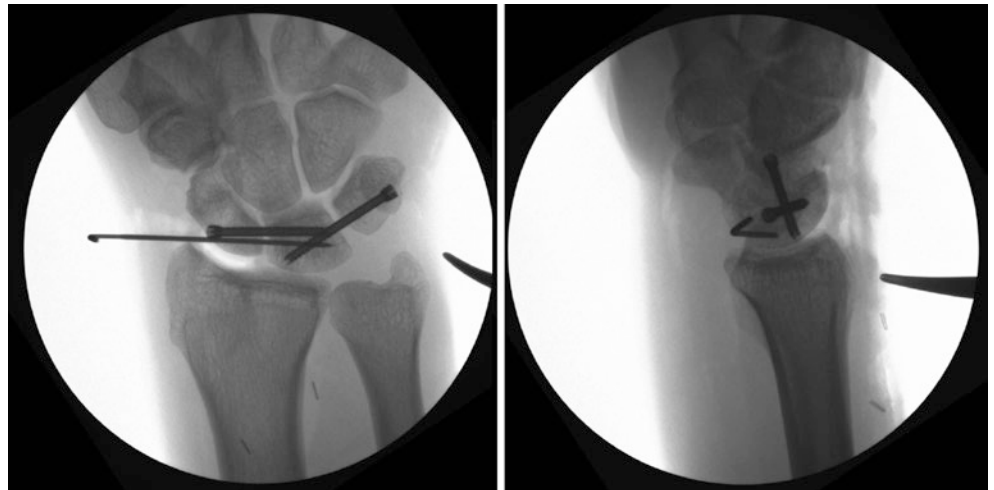
**Fig. 25.30** Interosseous wires passed for ligament repair, with sutures and joystick in the lunate



**Fig. 25.31** Intraoperative radiographs with joystick, guidewire, and Kirschner wires (K-wires) positioned



**Fig. 25.32** Scapholunate screw with guidewire advanced to facilitate retrieval if sheared and to prevent migration



**Fig. 25.33** Lunotriquetral screw insertion



**Fig. 25.34** Scapholunate ligament suture tied over lunate (*arrow*)



**Fig. 25.35** Follow-up radiographs prior to K-wire removal

**Fig. 25.36** Follow-up radiographs after K-wire removal with complaints of pain in the index finger



**Fig. 25.37** CT scan of index metacarpal head revealing defect in the head of the capitate and mild scapholunate joint widening



### 25.4.2 Transscaphoid Perilunate Dislocations

Transscaphoid perilunate dislocations are approached dorsally, in a similar fashion to the pure perilunate dislocations. I still utilize a derotation K-wire in the scaphoid, and insert

the headless screw proximal to distal. Bone grafting from the distal radius may be required, and the scaphoid actually may need to be pieced back together with small K-wires and mini-fragment screws (Figs. 25.38, 25.39, and 25.40).

**Fig. 25.38** Scaphoid fracture (arrow) requiring bone graft





**Fig. 25.39** Multiple K-wire fixation of right scaphoid fracture



**Fig. 25.40** Multiple mini-fragment screws utilized for scaphoid fixation



Lunotriquetral joint stabilization is with the transarticular screw (Figs. 25.41 and 25.42).

**Fig. 25.41** (a) Injury radiographs of left transscaphoid perilunate dislocation. (b) Radiographs following open reduction internal fixation (ORIF) including use of a cannulated screw (not headless) in lunotriquetral stabilization, and a suture anchor in the radius to augment dorsal ligament repair. (c) Final radiographs



**Fig. 24.41** (continued)







**Fig. 25.42** (a) Injury radiographs of right transscaphoid perilunate dislocation. (b) Radiographs following ORIF. (c) Final radiographs revealing healed scaphoid and backing out of lunotriquetral screw



**Fig. 25.42** (continued)

Transradial styloid, transscaphoid perilunate, or transscaphoid-transcapitate combination fractures can also be approached dorsally, generally without the need for ligamentous repair of the scapholunate ligament. The carpal fractures associated with these injuries may be

addressed with K-wires, 1.0- or 1.3-mm screws, or small headless screws (Fig. 25.43). But even with good bone quality, good reductions, and acceptable fixation, sometimes the results are not as good as we would like or as we project (Fig. 25.44).



**Fig. 25.43** Triquetral fixation dorsally with a mini-fragment screw





**Fig. 25.44** (a) Injury radiographs of left forearm, demonstrating periunate injury. The patient had bilateral injuries. (b) Injury radiographs of right forearm, demonstrating periunate injury. (c) Traction radiographs of left wrist transscaphoid transcapitate transtriquetral fracture dislocation. (d) Traction radiographs of right transscaphoid periunate dislocation.

(e) Radiographs of left wrist following ORIF. (f) Radiographs of right wrist following ORIF. (g) Follow-up radiographs demonstrating mid-carpal collapse ulnar translocation and scapholunate widening of the left wrist. (h) Follow-up radiographs of the right wrist



**Fig. 25.44** (continued)



**Fig. 25.44** (continued)





**Fig. 25.44** (continued)

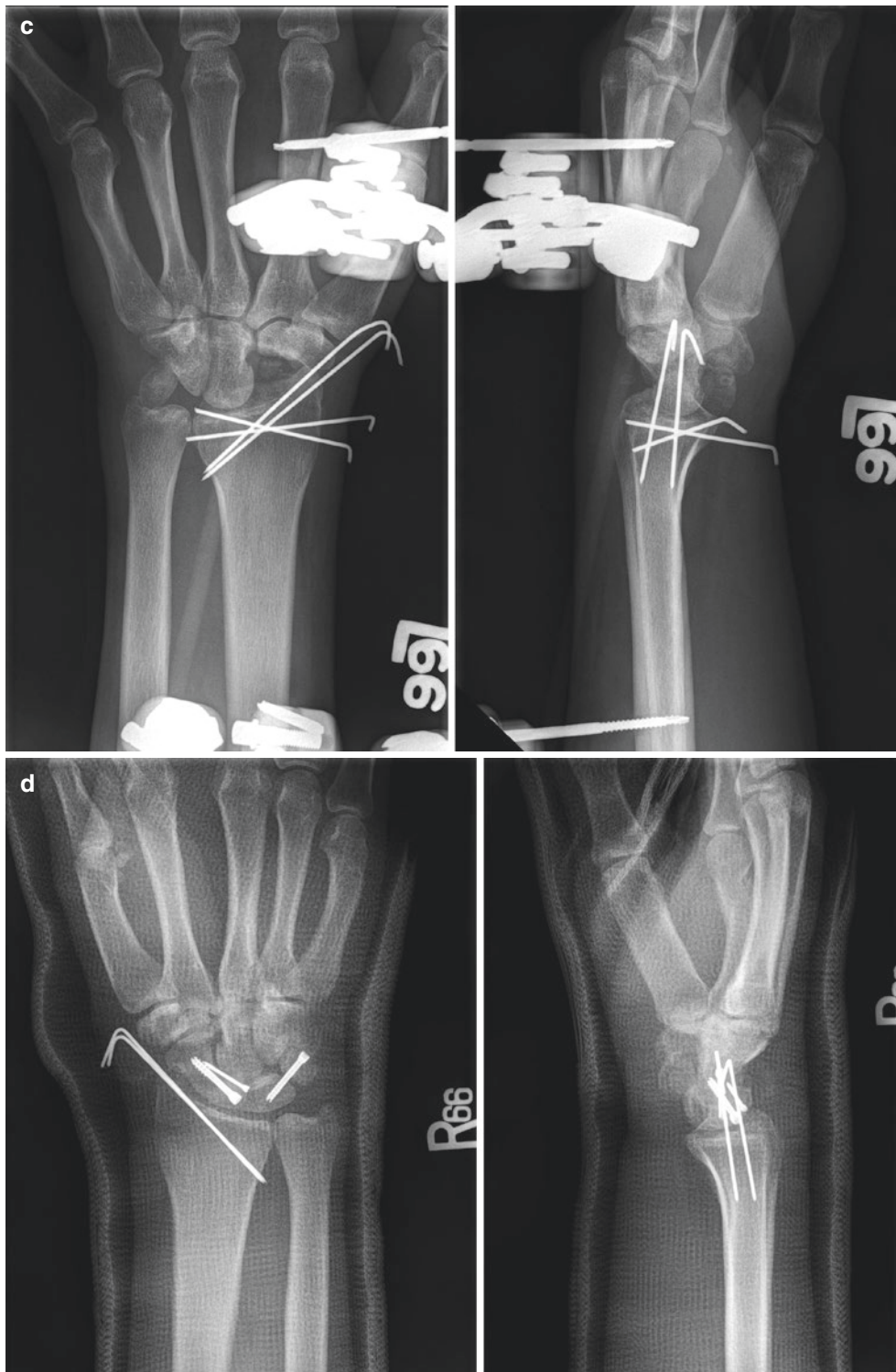
If concomitant injuries are present with scaphoid fracture and scapholunate ligament disruption, acute salvage operations, proximal row carpectomies, or fusions need serious

consideration (Figs. 25.45 and 25.46). Open reduction, fixation, and ligament repair or reconstruction does not work well.



**Fig. 25.45** (a) Injury radiographs of left transscaphoid perilunate dislocation with displaced, devitalized proximal pole of the scaphoid. (b) Patient's right wrist. With transstyloid, transscaphoid perilunate dislo-

cation. (c) Radiographs following proximal row carpectomy. (d) Radiographs following ORIF of the right wrist



**Fig. 25.45** (continued)



**Fig. 25.46** (a) Radiographs of right transscaphoid perilunate dislocation on transfer, with proximal displaced, devitalized proximal pole of the scaphoid. (b) Radiographs at 6-month follow-up after proximal row carpectomy



Union rates for scaphoid fractures in perilunate injuries without associated ligament injuries are surprisingly high, however, despite the significant displacement and injuries to the carpus. A review of early reports (with K-wires only, before the days of headless screws) showed an 85% union rate (29 of 34 patients) after ORIF with K-wires, whereas patients treated with closed reduction had a 50% rate of non-union (22 of 44) [22–26].

I do not routinely remove the lunotriquetral screws or the scapholunate screws, although some “windshield wiper” can be noted at the screw threads. I have been attempting to leave the transarticular fixations as long as possible, particularly on the lunotriquetral side, as I feel that doing so helps to prevent ligamentous attenuation and a PISI deformity.

The patients are counseled on the potential for limited range of motion and strength. They are encouraged to focus on functional restoration rather than trying to regain full, normal motion and normal strength.

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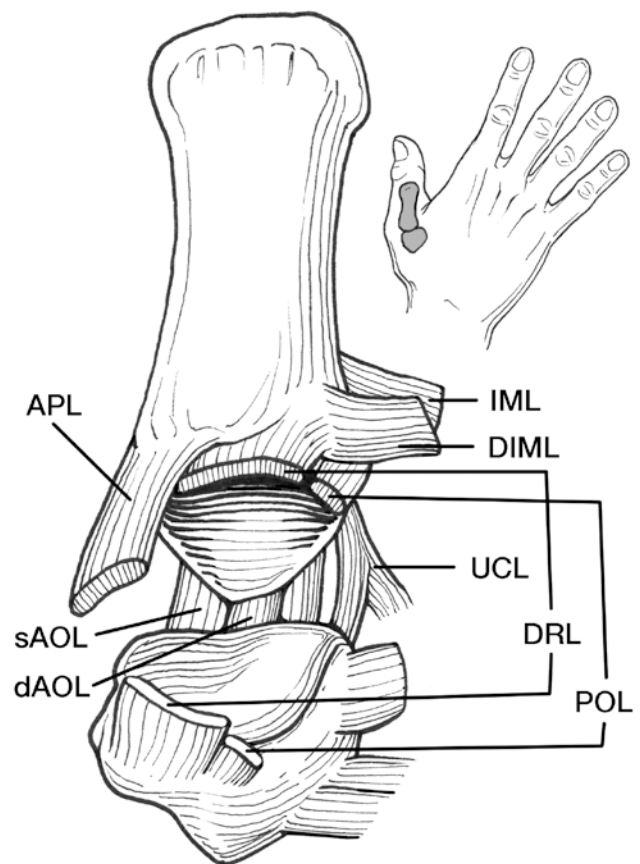
### 26.1 The Range of Carpometacarpal Joint Injuries

When I recently reviewed the PubMed registry, I found 371 dislocations and 270 fractures of the carpometacarpal joint. I did not read them all (a lot, but not all), but suffice it to say that they probably include any combination of dislocations, fractures, or fracture dislocations of the five carpometacarpal joints. This chapter cannot discuss all of the possibilities or anatomic nuances. It reviews the following injuries:

- Thumb dislocations
- Fracture dislocations (Bennett's)
- T-Intercondylar carpometacarpal fractures (Rolando's) (These eponyms have legs for recognition purposes.)
- Avulsion injuries of the index and long carpometacarpal joints
- Ring and small carpometacarpal joint injuries, including reverse Bennett's
- Multiple, two- to five-carpometacarpal fracture dislocations

### 26.2 Thumb Dislocations

One really must be amazed at how hand surgeons can give you nightmares from trying to get your head around all of the cited ligaments associated with the carpometacarpal joint of the thumb, let alone naming the darn things [1, 2]. Not to be disrespectful to the investigators of the anatomy and biomechanics of the thumb carpometacarpal joint, I will share a diagram of seven ligaments and focus on two (Fig. 26.1).



APL - abductor pollicis longus  
 sAOL - superficial anterior oblique ligament  
 dAOL - deep anterior oblique ligament  
 IML - intermetacarpal ligament  
 DIML - deep intermetacarpal ligament  
 UCL - ulnar collateral ligament  
 DRL - dorsoradial ligament  
 POL - posterior oblique ligament

**Fig. 26.1** Right thumb carpometacarpal (CMC) ligaments



Historically, the ligament given the most attention, interest, and credit for stability of the thumb has been the anterior oblique ligament, with the deep portion being most important. Recently, the dorsoradial ligament has stepped to the forefront as the prime stabilizer, particularly in the pronated, abducted position [3, 4]. The histological credibility of the anterior oblique ligament has been challenged by Ladd et al. [5, 6], who found it to be hypocellular and thin.

With this as a segue, we will begin with the carpometacarpal joint dislocations. Despite the saddle or bi-saddle joint structure of the thumb carpometacarpal joint and some inherent stability, thumb carpometacarpal joints can be readily re-dislocated after closed reduction. Closed treatment can succeed, but that has not been the “rule of thumb”; the results usually are not as stable as in Figs. 26.2 and 26.3.



**Fig. 26.2** Injury radiographs of left thumb CMC dislocation



**Fig. 26.3** Follow-up radiographs following closed reduction and nonoperative cast and splint treatment

Generally, something needs to be done to help stabilize the joint. Closed reduction, percutaneous pinning, open repair, open reduction with ligamentous reconstruction, and arthrodesis have all been utilized. For years, I used the acute ligamentous repair approach put forth by Simonian and Trumble [7], using a split flexor carpi radialis (FCR) passed through drill holes and then secured into the trapezium. The patients fared well and had very stable carpometacarpal joints.

After a casual conversation with a well-respected hand surgeon relative to the use of FCR reconstruction *versus* pinning, and the use of percutaneous K-wire fixation, I began performing open ligamentous repair for the unstable dislocations. The review of thumb carpometacarpal joint dislocations that have been cared for at Shock Trauma (including those treated by Dr. Raymond Pensy) revealed that 29 were treated. The distribution of approaches is shown in Table 26.1.

**Table 26.1** Treatment of carpometacarpal joint dislocations of the thumb at shock trauma

Treatment approach	Patients, <i>n</i>
Open repair	15
Open flexor carpi radialis (FCR) reconstruction	5
Open reduction, K-wire only	4
Closed reduction, percutaneous K-wire	2
Closed reduction, splint	1
Arthrodesis	1
Amputation	1

This table shows that open repairs have been performed three times as frequently as FCR reconstructions. The clinical results appear to be equal for open repair or FCR recon-

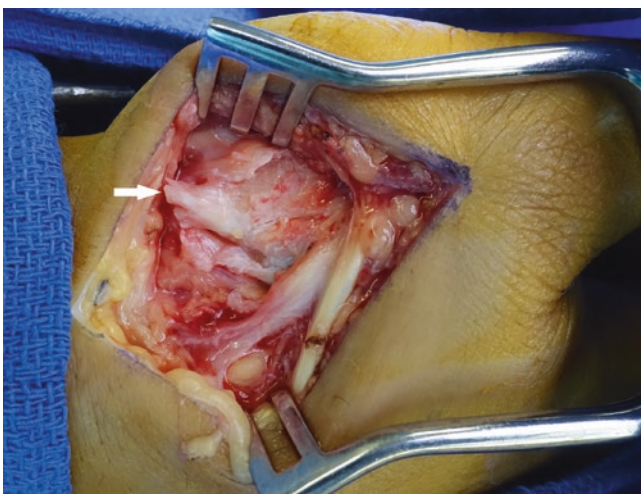
struction; we are unaware of any reconstruction being performed following acute repair (though it is granted that a review has not been performed). Thus, I now favor acute ligamentous repair.

Using the set-up, prep, and draping presented in Chap. 21, the approach is a straight dorsal approach over the carpometacarpal joint, which extends from about the mid-metacarpal of the thumb to the radial styloid. The extended incision is required to adequately mobilize the extensor pollicis longus and brevis, as well as to identify the radial artery, which crosses over the scaphotrapezial joint. The lesser capsular ligaments are usually avulsed off of the metacarpal base, but the stout dorsoradial ligament is frequently avulsed off the trapezium. Once the exposure is completed and the joint is cleared of hemarthrosis, holes are drilled through the base of the metacarpal and trapezium, with the passage of small wires (either 26- or 28-gauge) in a loop for passage of the sutures, which are placed in the ligaments. The suture is either absorbable (such as 2-0 or 3-0 PDS sutures) or nonabsorbable (3-0 Ethibond®), but the patient may complain about the knots regardless of the suture type.

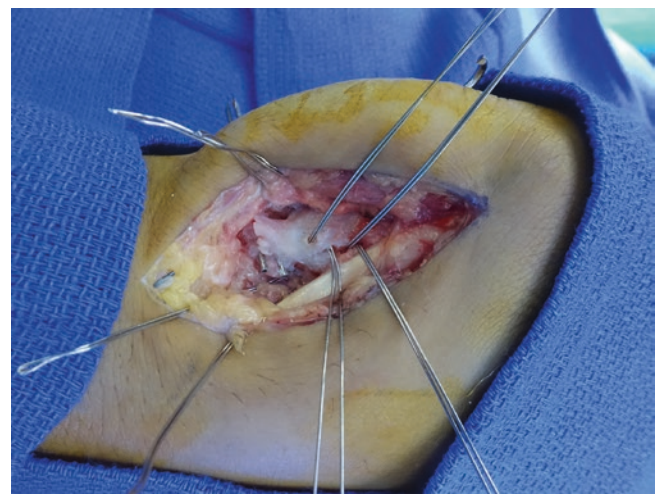
Prior to the passage of the sutures through the bones with the wire passers, K-wire fixation is performed, with antegrade placement of one or two K-wires through the metacarpal base for pre-positioning. The small wire sutures passers are passed through the drill holes prior to reduction of the joint, with the sutures placed through the loops of the wires, and then the K-wires advance so as not to inadvertently wrap up the sutures. Once the reduction is confirmed radiographically, the sutures are pulled through and then tied around the base of the metacarpal and the trapezium (Figs. 26.4, 26.5, 26.6, 26.7, 26.8, 26.9, 26.10, 26.11, 26.12, and 26.13).



**Fig. 26.4** Radiographs on presentation following motorcycle accident with painful swollen right thumb CMC with clinical instability. Radiographs demonstrate capsular avulsion after thumb was “popped” into place without dislocation radiograph (*arrow*)



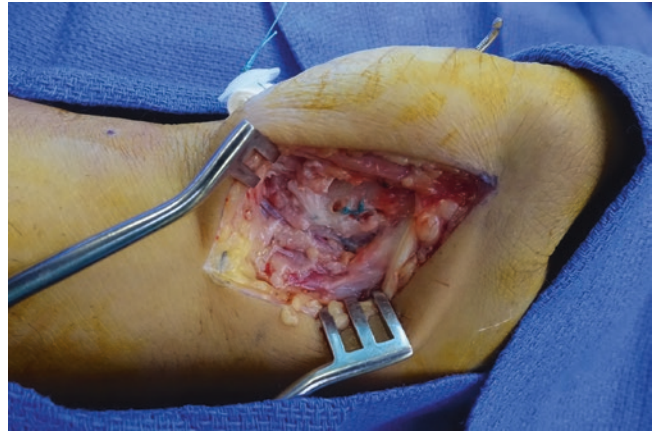
**Fig. 26.5** Intraoperative demonstration of avulsed dorsoradial ligament (DRL) (*arrow*)



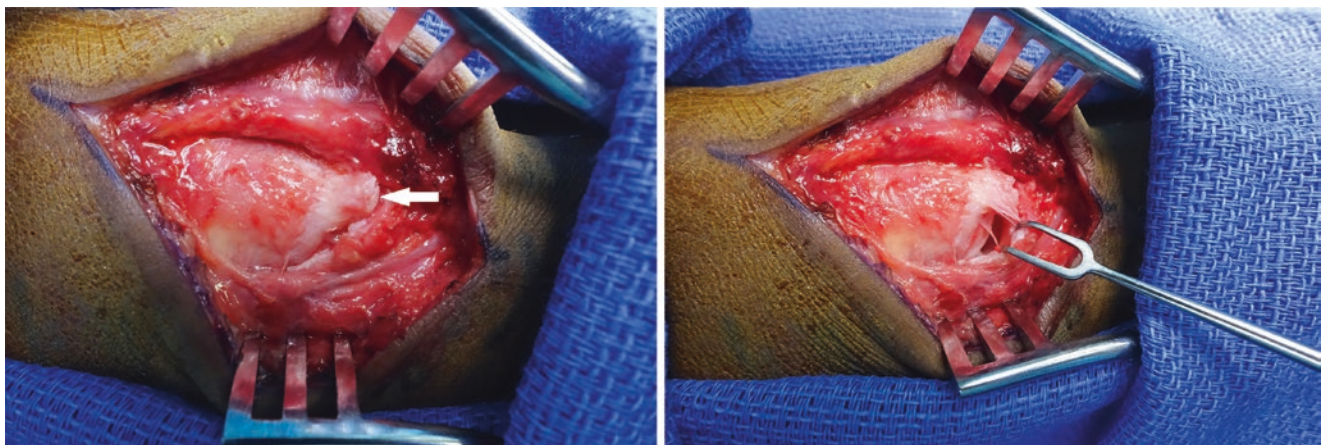
**Fig. 26.6** Wire loops placed through holes in metacarpal and trapezium for sternum passage. 18-gauge needles used for drills and 28-gauge wire will be passed through for DRL repair as well as posterior oblique ligament repair with the joint reduced and K-wired



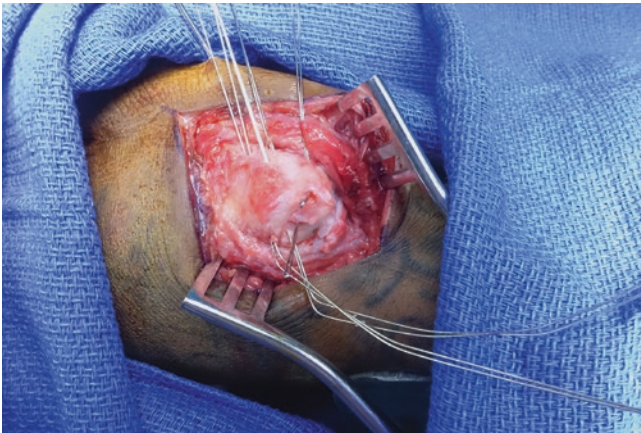
**Fig. 26.7** Sutures passed and tied, including DRL tied over button



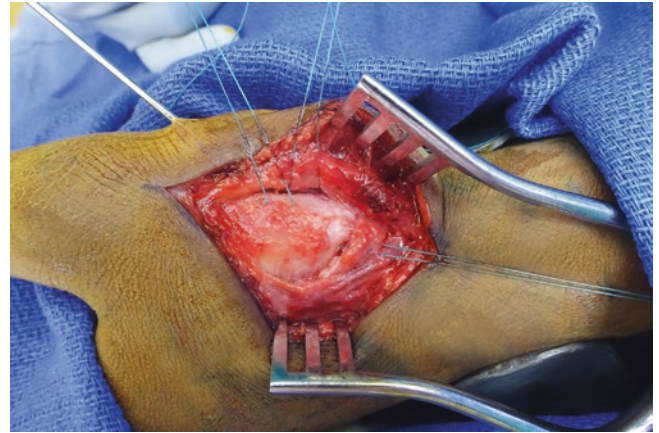
**Fig. 26.8** Injury radiographs of left thumb CMC dislocation



**Fig. 26.9** Intraoperative finding of DRL avulsion (arrow)



**Fig. 26.10** Wires positioned for passage of sutures

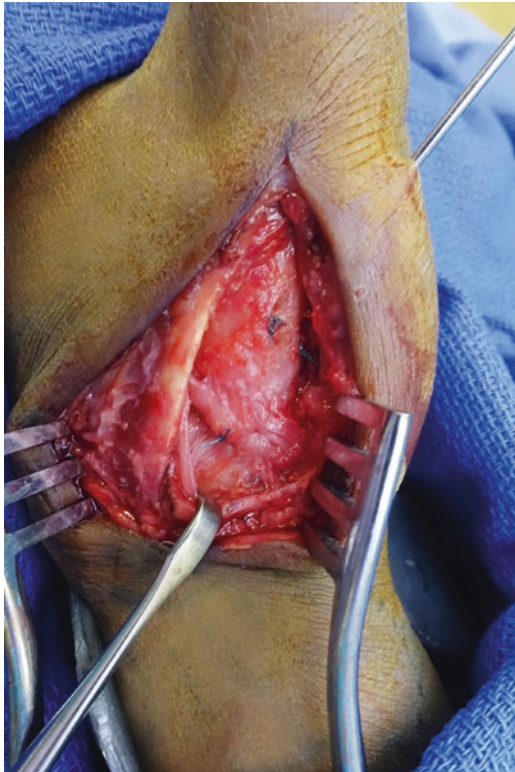


**Fig. 26.11** Sutures (3-0 Ethibond®) fed through holes



**Fig. 26.12** Intraoperative radiographs demonstrating joint reduction and K-wire fixation





**Fig. 26.13** Joint reduced and held with K-wire; sutures tensioned and tied

The K-wires are bent and cut; they remain in place for about 6 weeks, along with a short arm cast. At 6 weeks, the K-wires are removed, a short opponens splint is fabricated, and range of motion is undertaken (with the splint removed) for 2 weeks. During the next 2 weeks, the splint is off during the day to work on strengthening, but it is worn at night. At the end of those 2 weeks, the patient is allowed unrestricted activity.

### 26.3 Carpometacarpal Joint Fracture Dislocations (Bennett Fractures)

Carpometacarpal joint fracture dislocations, Bennett fractures, are approached with the concept that the anterior oblique ligament does have a level of importance and is attached to the fragment of the metacarpal, which stays in the anatomic position when the base dislocates [8]. Two conventional philosophies about the treatment of this injury are that the adductor pollicis will adduct the thumb, and the abductor pollicis longus will proximally displace the metacarpal. The reduction maneuver is longitudinal traction and pronation, abduction, and radial-to-ulnar pressure to reduce the base (Fig. 26.14). Another concept, proposed by Edmunds [9], is that reduction can be performed by using a “screw home” technique, where simply pronating the thumb will actuate the reduction [9].



**Fig. 26.14** Reduction maneuver for right thumb CMC fracture dislocation: longitudinal traction, pronation, abduction, and ulnar pressure applied at the metacarpal base

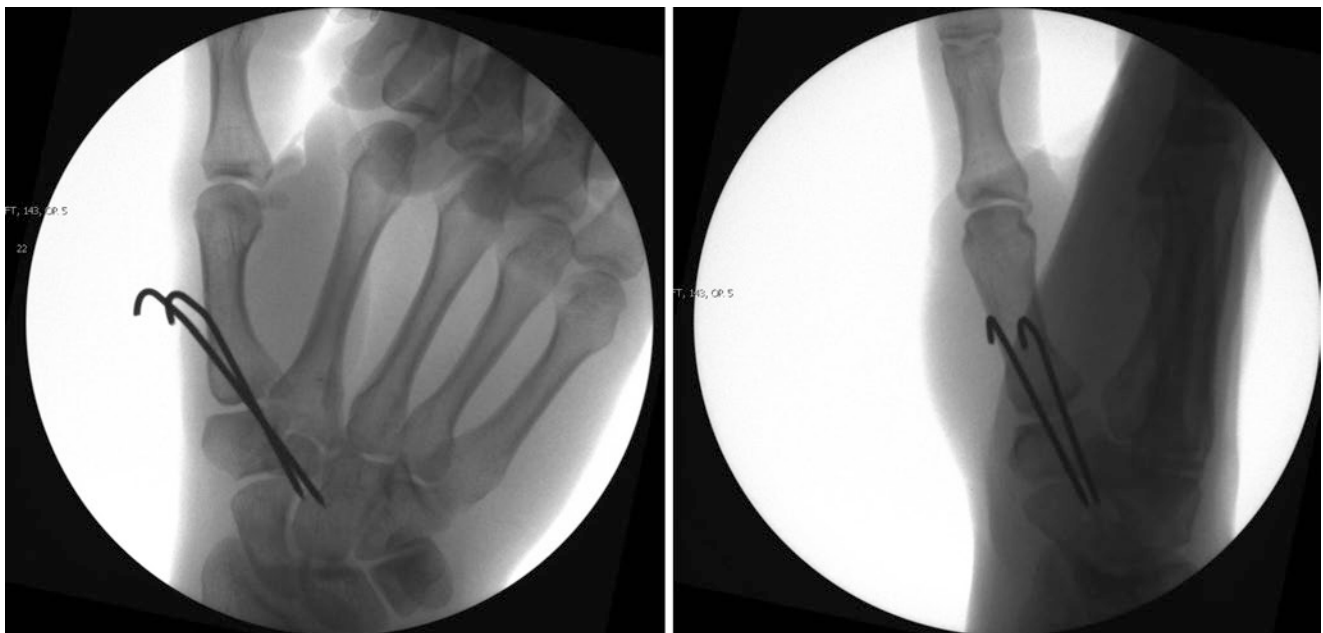


Regardless of approach one adopts, the necessity of joint reduction is paramount. Following the reduction maneuver, stabilization is generally undertaken with percutaneous K-wire fixation. I typically use two K-wires, one 0.0625 and then 0.045 (to prevent rotation), because many of our patients have multi-system injuries and I would like more stability to enable weight-bearing and use

of their hand. Further controversy exists as to whether the palmar fragment requires fixation. I urge caution in trying to percutaneously fix the smaller fragments, as they can be easily displaced. Also, if reduction of the CMC joint is attained and the fracture is reduced, whether the fragment must be secured is questionable (Figs. 26.15, 26.16, 26.17, and 26.18).



**Fig. 26.15** Injury radiograph of left thumb Bennett fracture: CMC fracture dislocation with anterior oblique ligament fragment (*arrow*)



**Fig. 26.16** Fixation attained during closed reduction. Percutaneous K-wires are not in the fragment, after an attempt at K-wire fixation had occurred with fragment displacement



**Fig. 26.17** Injury radiographs of right thumb with large anterior oblique ligament fragment (*arrow*)



**Fig. 26.18** Fixation following closed reduction: percutaneous fixation including into displaced anterior oblique fragment, which needed to be reduced and required K-wire fixation to maintain reduction

Occasionally open reduction internal fixation (ORIF) is required, particularly for those injuries that are addressed late. I have found that the percutaneous K-wire has fared very well, even with ORIF; only occasionally have I used screws. I do know of proponents of arthroscopic fixation, including percutaneous screw fixation, but I have no experience in this realm. The approach is an L-type incision along the thenar eminence, elevating the abductor pollicis brevis

and preserving the sensory branches (Figs. 26.19, 26.20, 26.21, 26.22, 26.23, 26.24, 26.25, 26.26, 26.27, 26.28, 26.29, and 26.30). The question arises as to how precise the reduction needs to be. Cullen et al. [10] have demonstrated that even 2 mm of step-off can be well tolerated. In fact, the joint contact area increases and is shifted dorsally with 2 mm displacement of the anterior oblique fragment.



**Fig. 26.19** Incision outlined for anterior approach to left thumb carpometacarpal joint



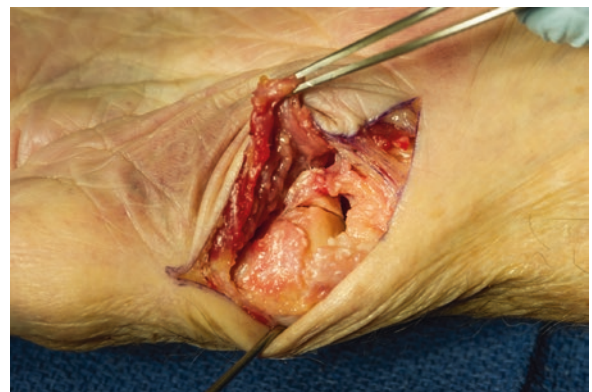
**Fig. 26.21** Abductor pollicis brevis elevated off of the metacarpal and CMC; sensory branches are preserved ulnarly (arrow)



**Fig. 26.20** Sensory branches of superficial branch of the radial nerve crossing incision

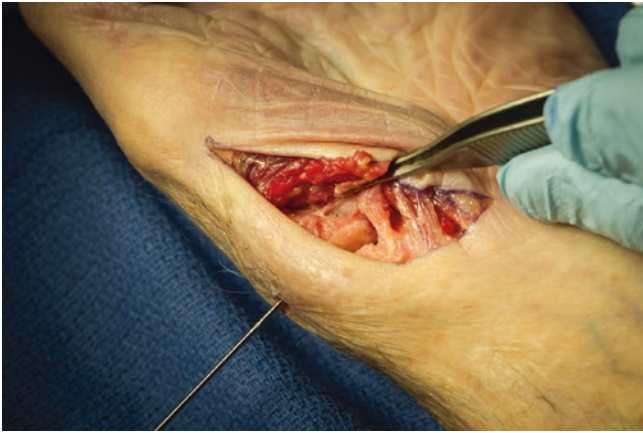


**Fig. 26.22** CMC joint opened

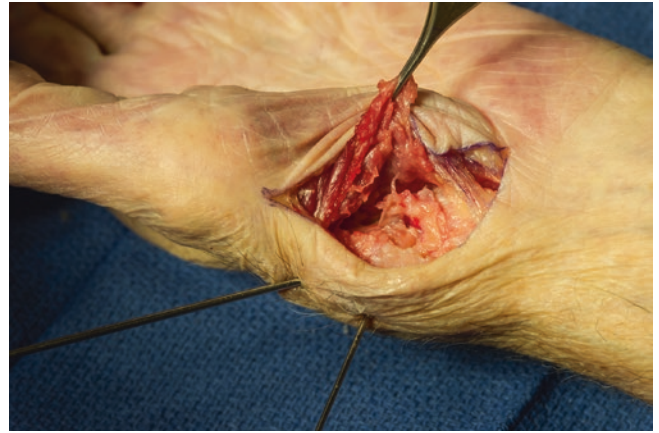


**Fig. 26.23** Palmar "beak" fragment with anterior oblique ligament fragment osteotomized, "fractured"





**Fig. 26.24** Fragment reduced and stabilized with 0.045-in. K-wire



**Fig. 26.25** Thumb metacarpal base reduced and stabilized to trapezium with K-wire



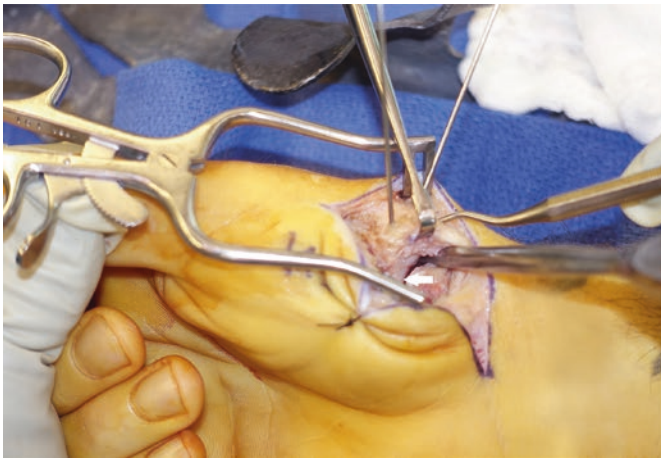
**Fig. 26.26** Injury radiographs of right thumb CMC fracture dislocation with delayed presentation



**Fig. 26.27** Incision approach to right thumb chronic displaced CMC fracture dislocation



**Fig. 26.28** Dental pick in mobilized fracture



**Fig. 26.29** Reduction and K-wires stabilizing fracture (*arrow*)



**Fig. 26.30** Intra-operative radiograph during open reduction internal fixation (ORIF) of right thumb CMC fracture dislocation

I generally leave the pins in place for 6 weeks, followed by the use of a short opponens splint for 2 weeks, followed by strengthening and then unrestricted activity.

## 26.4 T-Intercondylar Carpometacarpal (Rolando's) Fractures

The final thumb base injury is the T-intercondylar comminuted Rolando's fracture. If one is fortunate enough to have large fragments, then ORIF with lag screws in place certainly is attractive (Figs. 26.31 and 26.32).



**Fig. 26.31** Injury radiograph of right wrist with thumb metacarpal demonstrating T-type Rolando's fracture

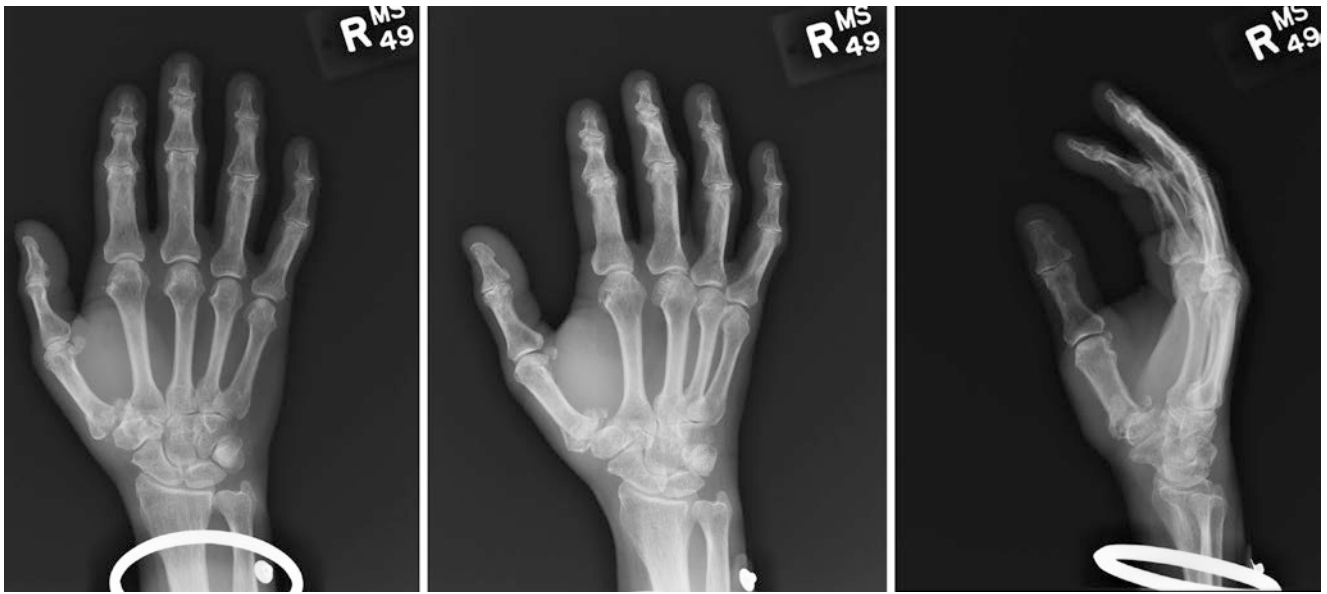




**Fig. 26.32** Intraoperative radiographs following ORIF

Unfortunately, many patients will have notable comminution; in these cases, I have utilized external fixation with either a triangular frame from the index to the thumb, or a unilateral frame using half pins in the trapezium and metacarpal shaft. The radial artery must be visualized so that inadvertent injury can be avoided. I use a straight incision

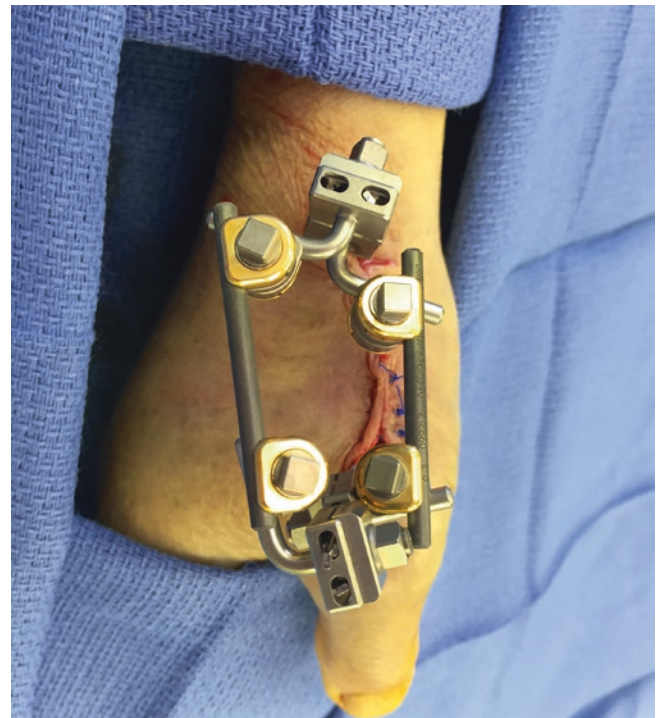
over the thumb metacarpal base, carpometacarpal joint and trapezium, followed by internal fixation. Fixation includes plates, screws, percutaneous wires, or interosseous wires (Figs. 26.33, 26.34, 26.35, 26.36, 26.37, 26.38, 26.39, 26.40, and 26.41).



**Fig. 26.33** Injury radiographs of T-intercondylar fracture of right thumb metacarpal base

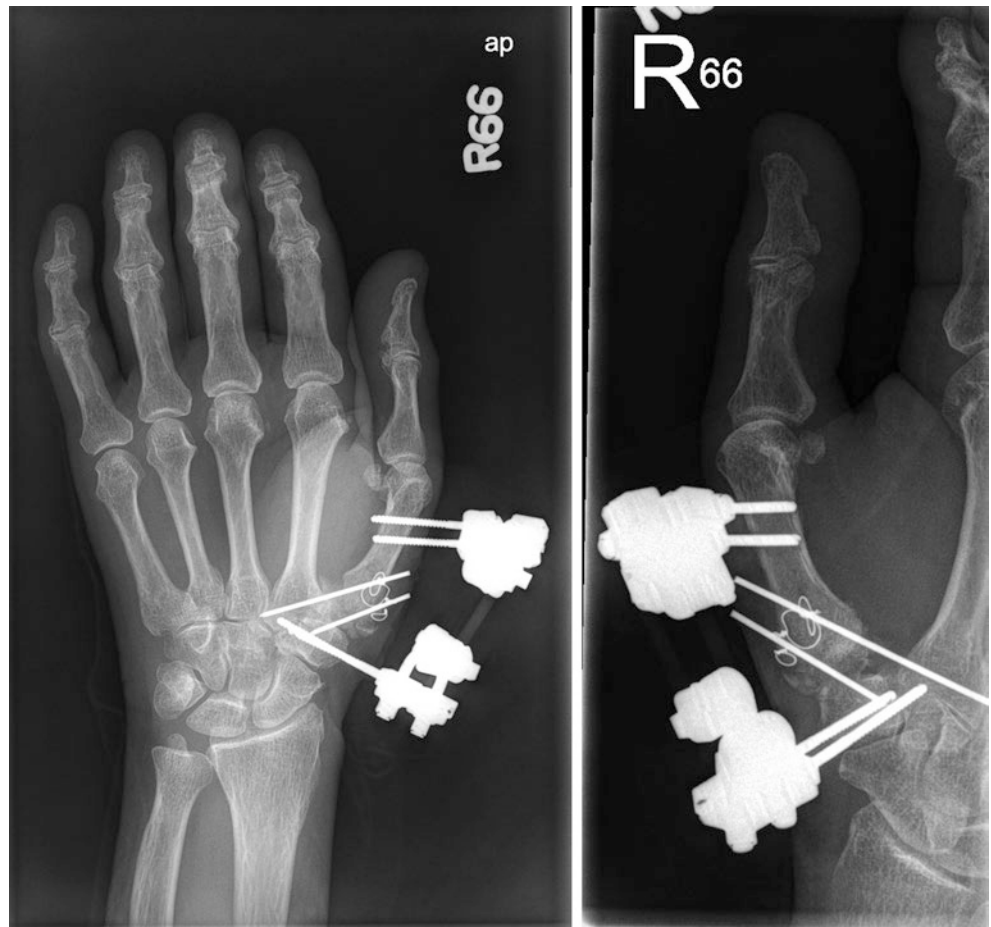


**Fig. 26.34** Surgical approach for ORIF and external fixation with radial artery adjacent to external fixator half pin (*arrow*)



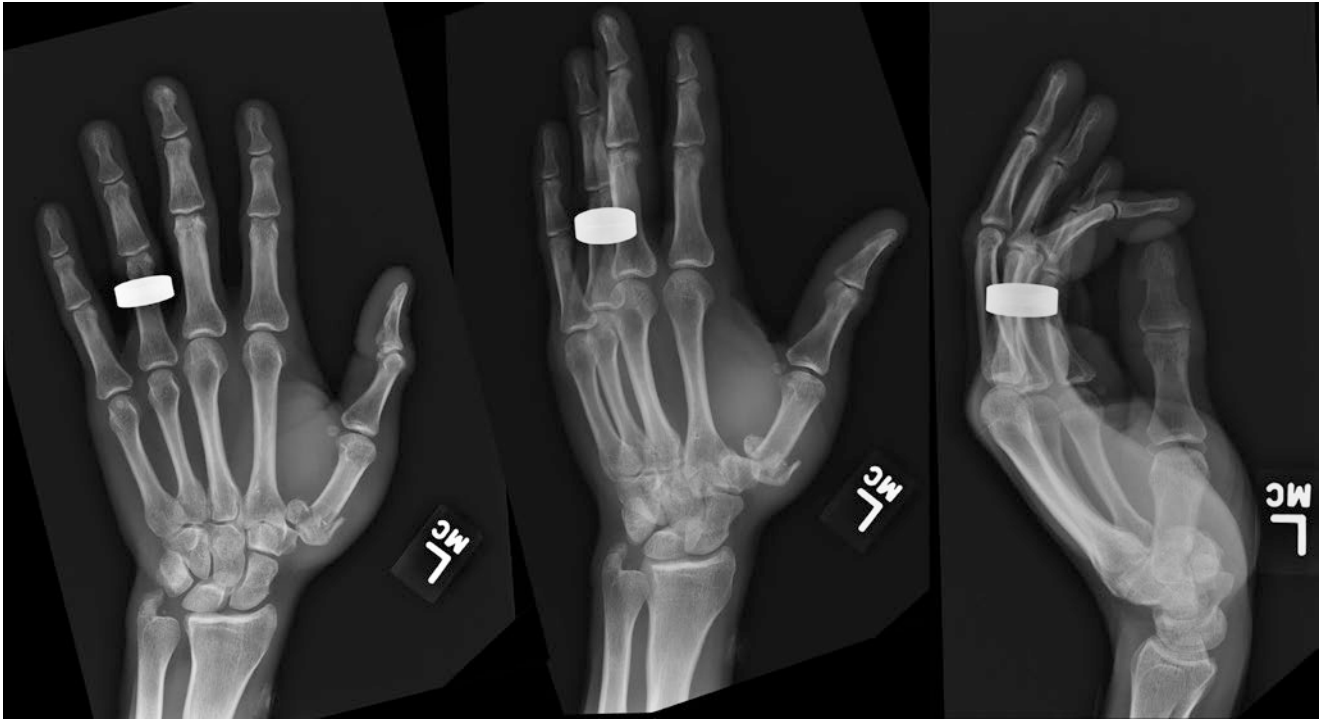
**Fig. 26.35** Final construct of external fixator maintained for 6 weeks

**Fig. 26.36** Follow-up radiographs after ORIF/external fixation and percutaneous fixation

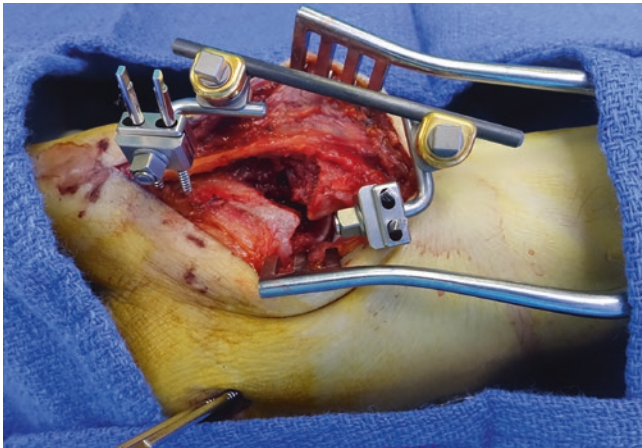


**Fig. 26.37** Final radiographs at time of discharge with stable, functional shaft thumb CMC

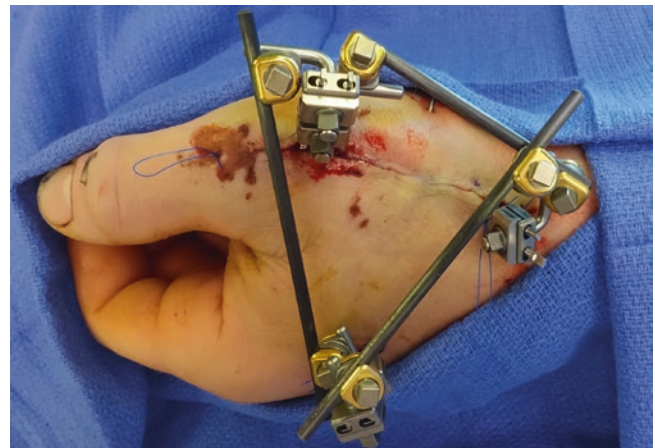




**Fig. 26.38** Injury radiograph of left thumb T-intercondylar fracture



**Fig. 26.39** External fixator with pins in trapezium and metacarpal for ORIF of left thumb T-intercondylar fracture



**Fig. 26.40** Triangular frame constructed and utilized because of bone quality and concern over depending on internal fixation only



**Fig. 26.41** Intraoperative radiograph following ORIF/external fixation and percutaneous fixation, with slight dorsal translation of shaft on bone

The external fixator, if utilized, remains in place for about 6 weeks, followed by range of motion for 2 weeks, strengthening for 2 weeks, then use and weight-bearing as tolerated.

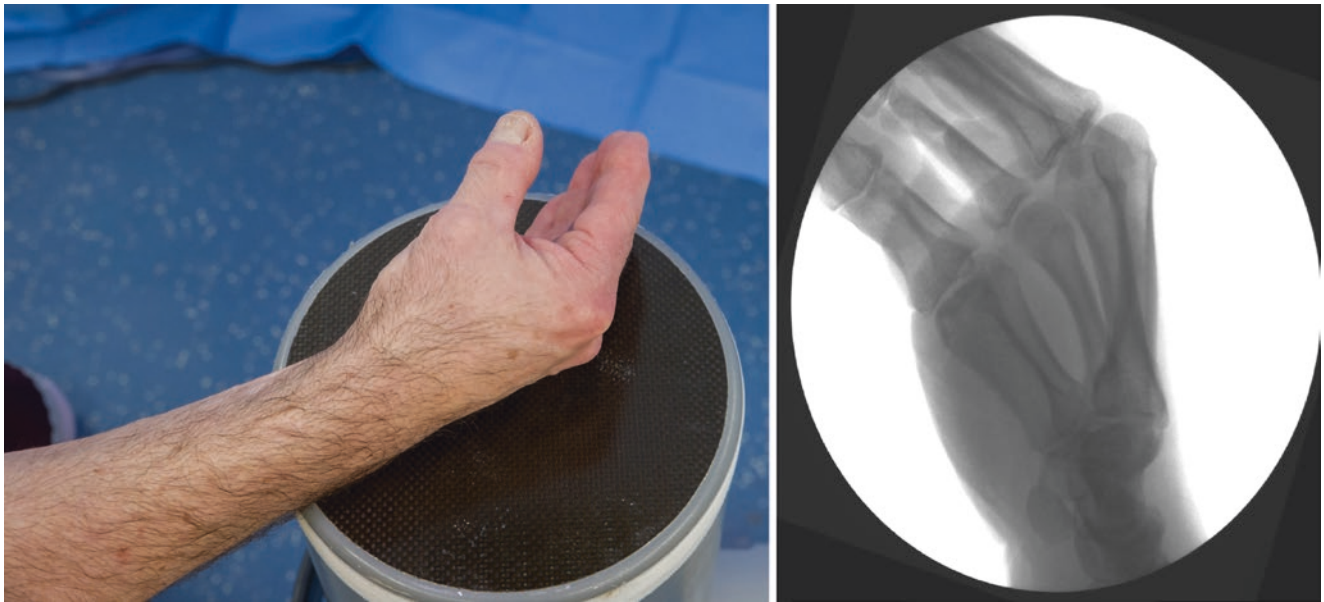
## 26.5 Injuries of the Index and Long Carpometacarpal Joints

Index and long carpometacarpal joint injuries can be difficult to visualize, but they are not very common. An impor-

tant issue is the pull of the extensor carpi radialis longus and brevis, and the tendency for these base fractures to be associated with dorsal subluxation [11]. To visualize these injuries, specific radiographs need to be obtained. Posteroanterior (PA) radiographs may need to be slightly pronated, whereas the lateral radiographs need to be slightly supinated, thus allowing tangential views to be obtained (Figs. 26.42 and 26.43).



**Fig. 26.42** (a) Oblique posteroanterior (PA) view for index/long CMCs. (b) PA radiograph slightly oblique for index/long CMC view



**Fig. 26.43** (a) Tangential lateral view radiograph for index/long CMCs. (b) Lateral radiograph for index/long CMC

Rarely, an isolated sliver of bone may be seen, particularly in the index metacarpal, where the extensor carpi radialis

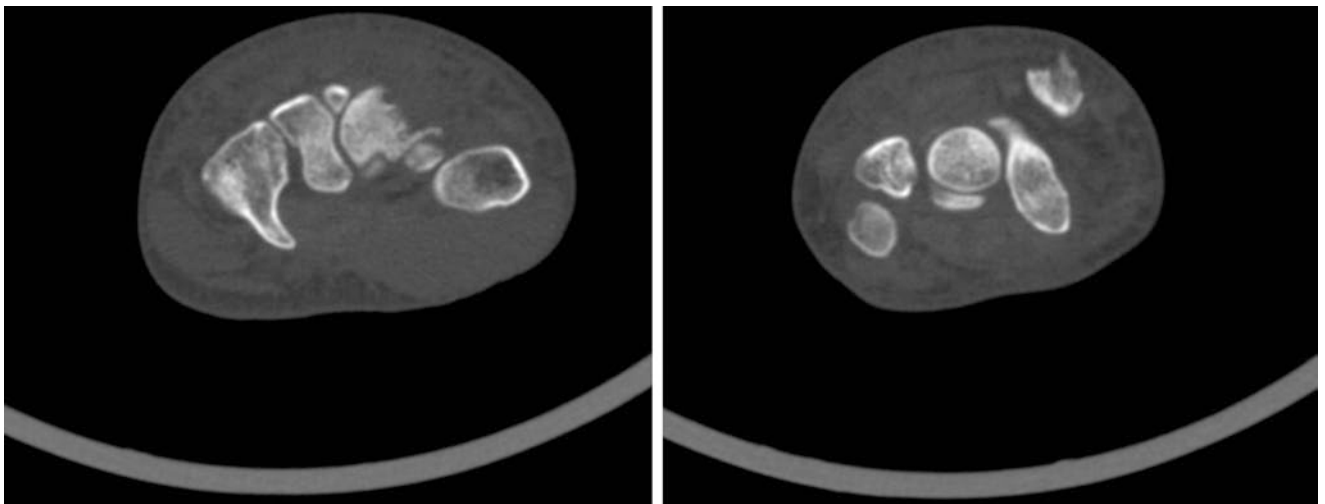
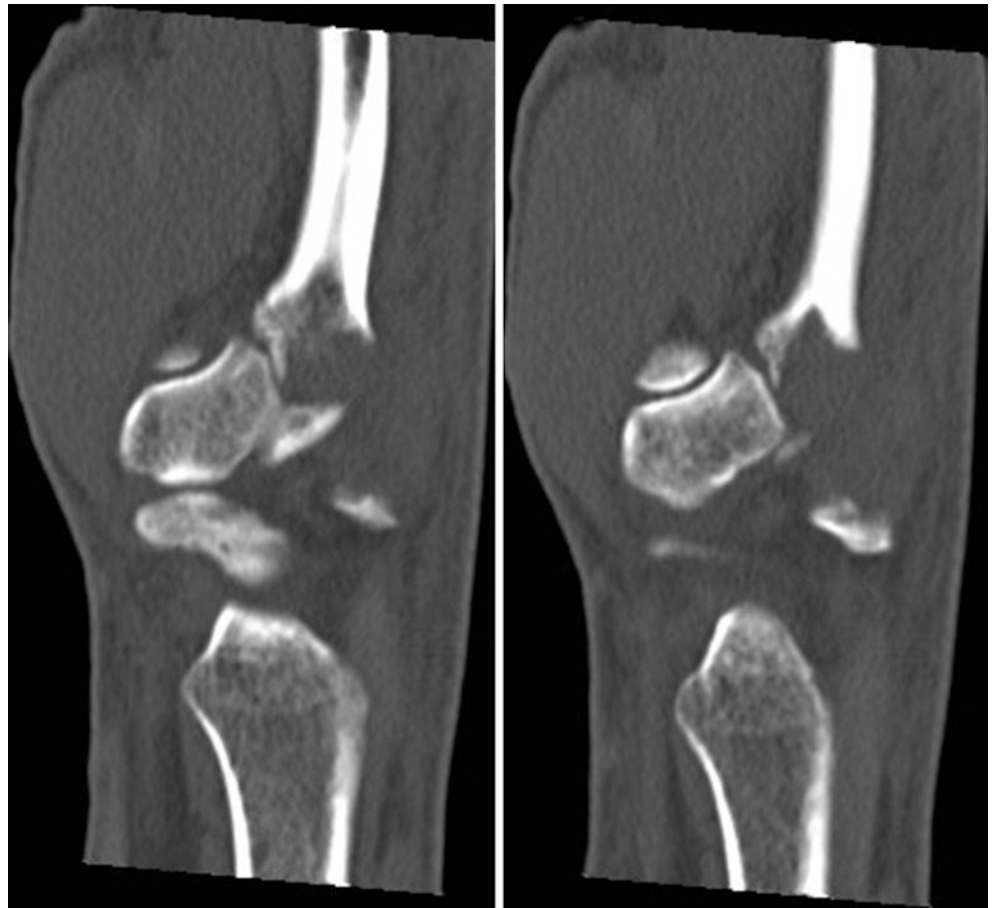
longus is inserted and is pulled off (Figs. 26.44, 26.45, and 26.46).



**Fig. 26.44** Injury radiographs of right wrist, demonstrating a defect in the index metacarpal base (*white arrow*) and an avulsion extensor carpi radialis longus fragment (*grey arrow*)



**Fig. 26.45** CT scan demonstrating fragment and index metacarpal base defect



**Fig. 26.46** CT scan demonstrating fragment and index metacarpal base defect

More commonly, the bases are subluxated dorsally, necessitating K-wire fixation as well as plate fixation. I generally use a straight incision over the area between the index and

long metacarpals to gain access to the fractures (Figs. 26.47, 26.48, 26.49, 26.50, and 26.51).

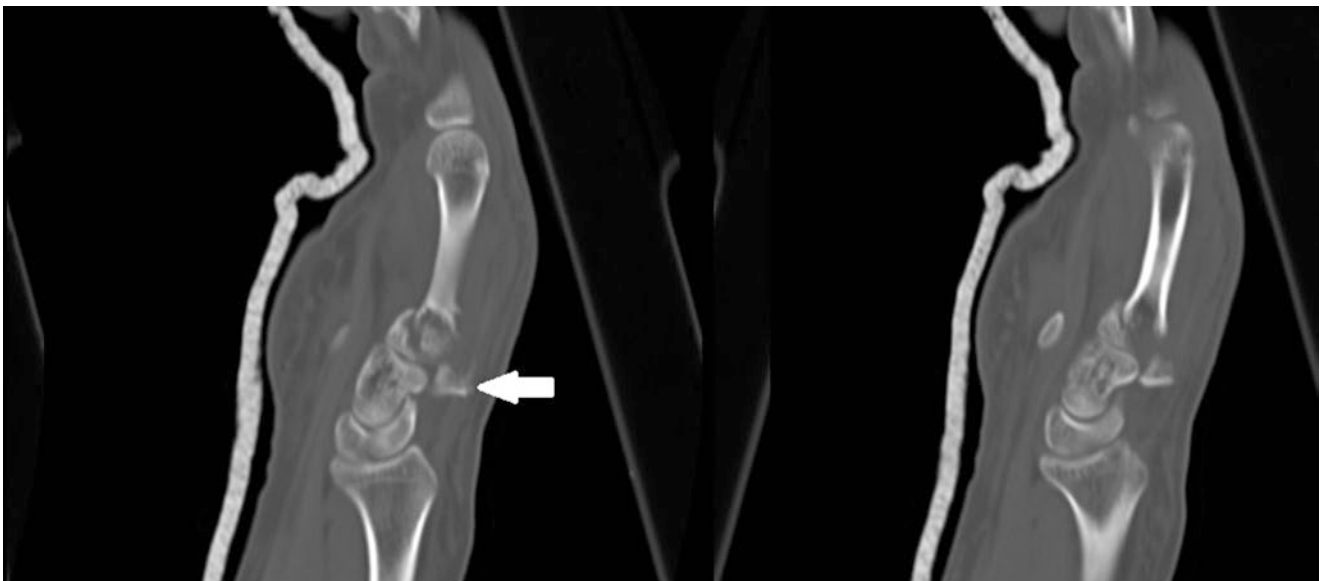
**Fig. 26.47** Injury radiographs demonstrating index metacarpal base fracture consistent with extensor carpi radialis longus insertion fracture (*arrow*)



**Fig. 26.48** Radiographs following ORIF. Note staples utilized for skin grafting secondary to proximal forearm injury



**Fig. 26.49** Injury radiographs demonstrating long metacarpal base fracture with possible extensor carpi radialis longus fragment avulsion



**Fig. 26.50** CT scan further revealing avulsed fragment (*arrow*)





**Fig. 26.51** Radiographs following fixation, including stabilization of adjacent CMCs found to be unstable intraoperatively

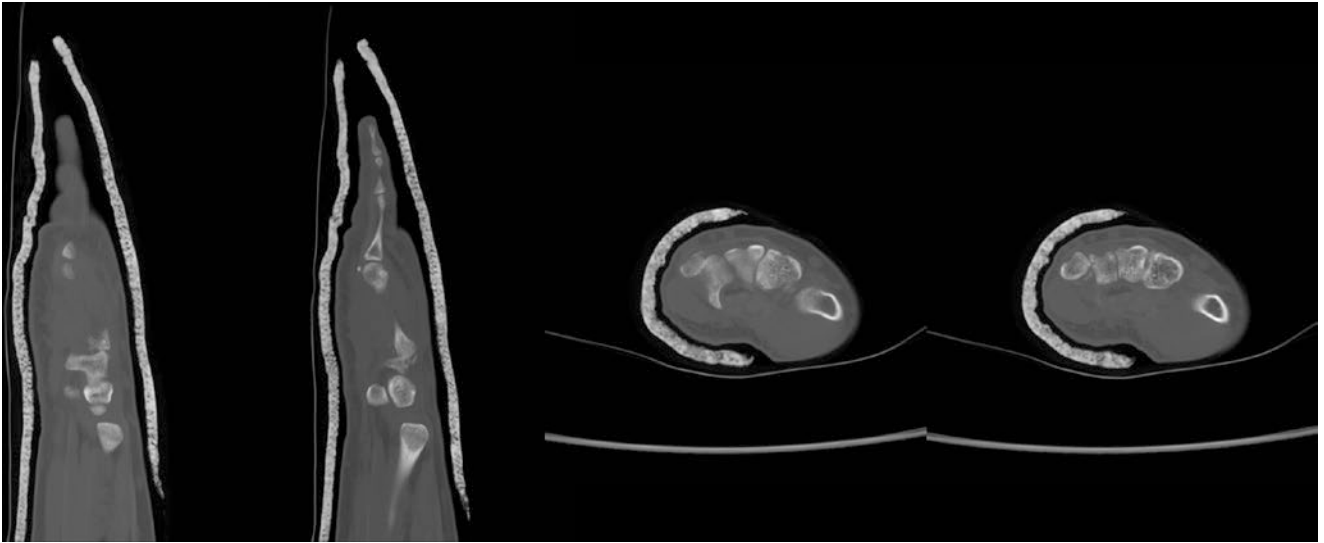
## 26.6 Injuries of the Ring and Small Carpometacarpal Joints

The carpometacarpal joints of the ring and small fingers, which are very mobile, have a couple of nuances. First, if there is a ring fracture (particularly a shaft fracture), close

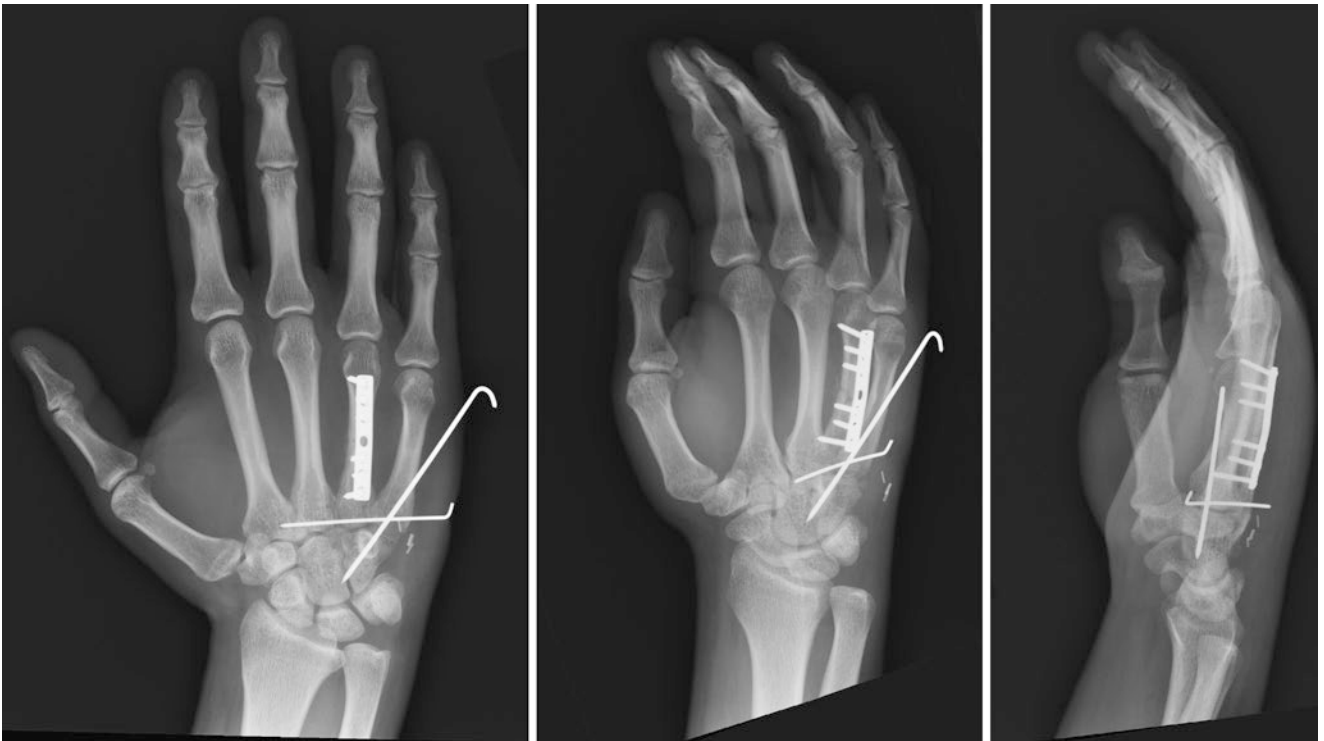
attention must be paid to the base of the small finger, as the ring can be a marker for a small metacarpal injury [12] (Figs. 26.52, 26.53, and 26.54). On the other hand, when a small metacarpal base fracture dislocation is appreciated, injury to the ring base and shaft needs to be further analyzed; CT scans occasionally are needed for this purpose.



**Fig. 26.52** Injury radiographs demonstrating ring metacarpal shaft fracture and small CMC dorsal subluxation seen on tangential lateral view with avulsion of dorsal rim of the hamate (arrow)

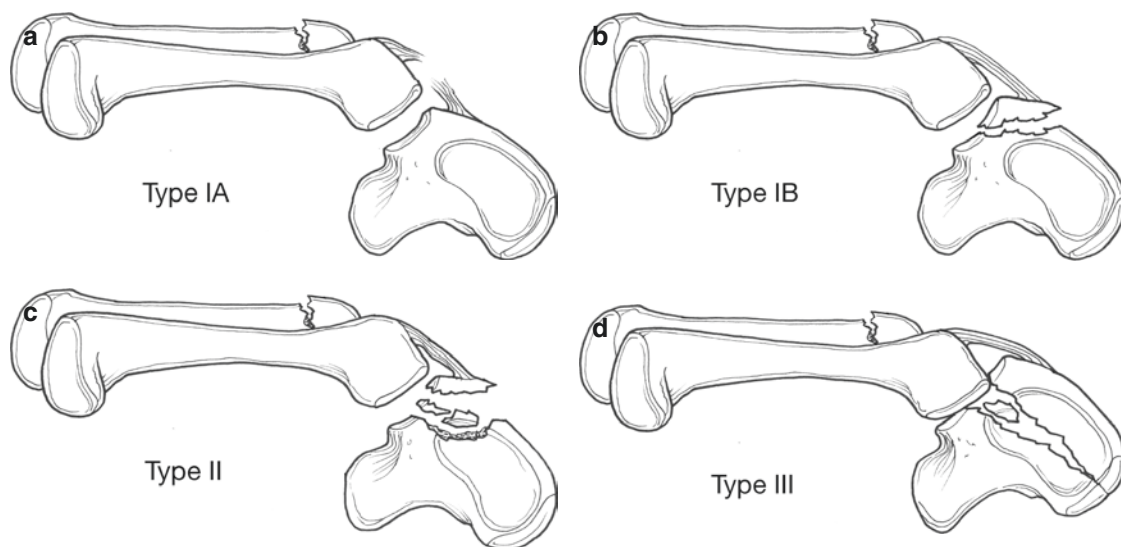


**Fig. 26.53** CT scan confirming small CMC fracture dislocation



**Fig. 26.54** Follow-up radiographs after ORIF

Cain *et al.* [13] have a classification system that is notable for fracture designation but does not impart a lot of information for treatment (Fig. 26.55).



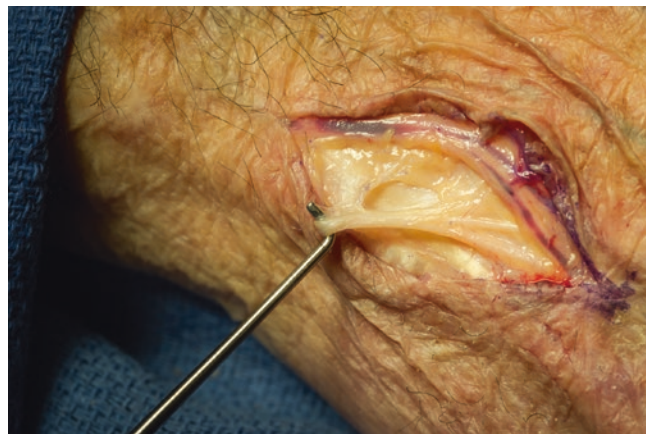
**Fig. 26.55** Carpometacarpal fracture dislocation classification of small finger CMC and associated ring metacarpal shaft fracture

I find that the results of closed reduction are rarely stable, particularly when there is any fracture including little avulsions, thus necessitating at least percutaneous K-wire fixation.

The more comminuted and unstable injuries require ORIF (Figs. 26.56, 26.57, 26.58, 26.59, 26.60, 26.61, 26.62, 26.63, 26.64, 26.65, and 26.66).



**Fig. 26.56** Longitudinal incision for approach to the right ring and small CMC joints



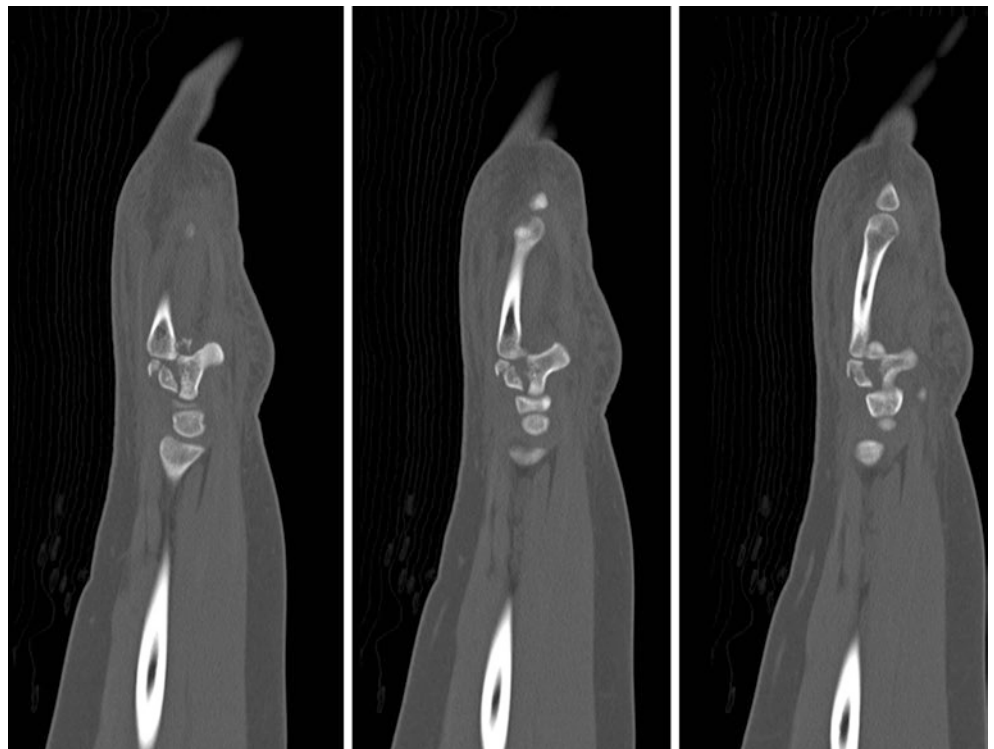
**Fig. 26.57** Dorsal sensory nerve branch of the ulnar nerve crossing the surgical field



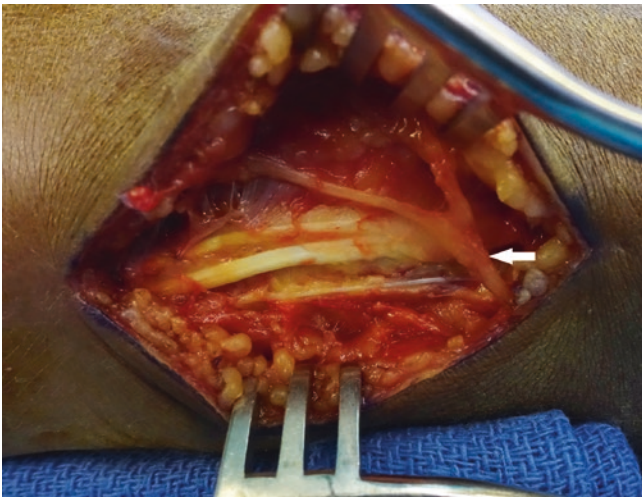
**Fig. 26.58** Exposed hamate and ring and small metacarpal bases



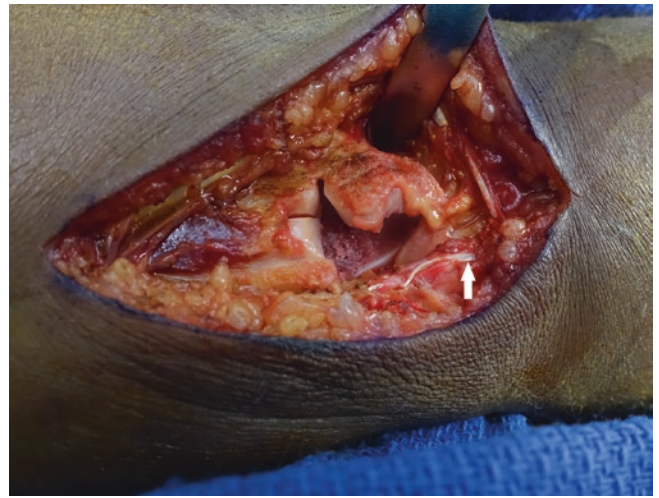
**Fig. 26.59** Injury radiographs of left ring and small CMC fracture dislocation with split hamate



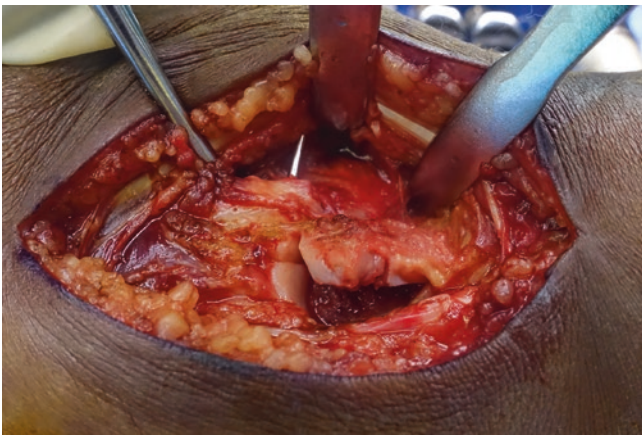
**Fig. 26.60** CT scan showing split hamate



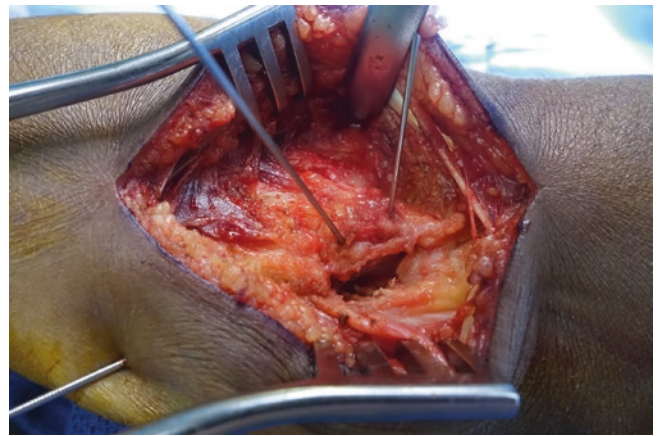
**Fig. 26.61** Approach to left ring and small CMC joint, showing the sensory branch of the ulnar nerve (*arrow*)



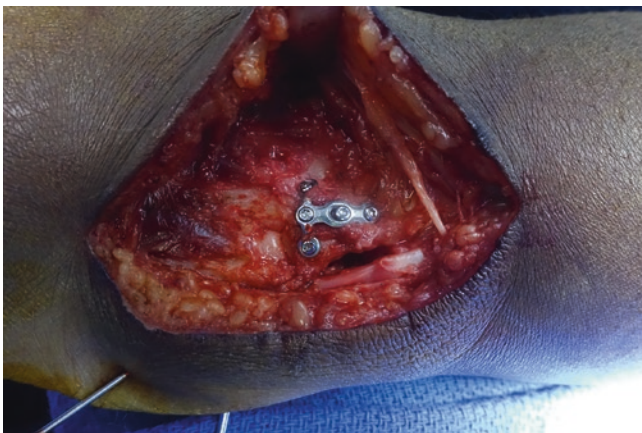
**Fig. 26.62** Extensor digiti minimi (*arrow*). Dorsal half of split hamate elevated



**Fig. 26.63** Ring and small metacarpal bases stabilized with transarticular, inside-out K-wire



**Fig. 26.64** Joints reduced and hamate reduced and held with K-wires



**Fig. 26.65** Definitive plating with contoured 1.5-mm locking plate





**Fig. 26.66** Radiographs following ORIF

In an effort to simulate these fractures, a study was done looking at axially loading the hand. In fact, the more common injury identified was injury to the long metacarpal base and capitate, rather than to the ring and small fingers [14]. The initial thought process would be that the ring and small fingers are injured in axial loads, such as fighting, but the injury process of fighting probably involves more of a tangential blow to the ring and small fingers rather than an axial load to the hand, as in a roundhouse punch. (Boxers tend to punch straight and would load more centrally.) Critical to diagnosing and understanding ring and small carpometacarpal joint injuries is the use of proper radiographic hand posi-

tioning. Well-intended radiology technicians will obtain palm-down PA and standard lateral radiographs, which unfortunately will tend to obscure the anatomy. Joint-specific films need to be obtained. The AP radiograph is actually a slightly pronated radiograph sometimes called the Catcher's Mitt or Allstate view (as in, "You're in good hands with Allstate"). The lateral radiographs need to be slightly pronated to obtain tangential views (Figs. 26.67 and 26.68). Unless you are using a C-arm and doing the positioning yourself, you will probably have to take a very active role in positioning the hand for the technician, because these are not standard views.



**Fig. 26.67** (a) Pronated position for AP view of ring/small CMCs. (b) AP radiograph for ring/small CMCs





**Fig. 26.68** (a) Pronated lateral position for tangential view of ring/small CMCs. (b) Lateral radiograph for ring/small CMCs

The metacarpal base of the small finger can be injured in an isolated fashion; this injury has been labeled the *reverse Bennett* fracture. The deforming force in this injury is the extensor carpi ulnaris attached to the small base and pulling the metacarpal

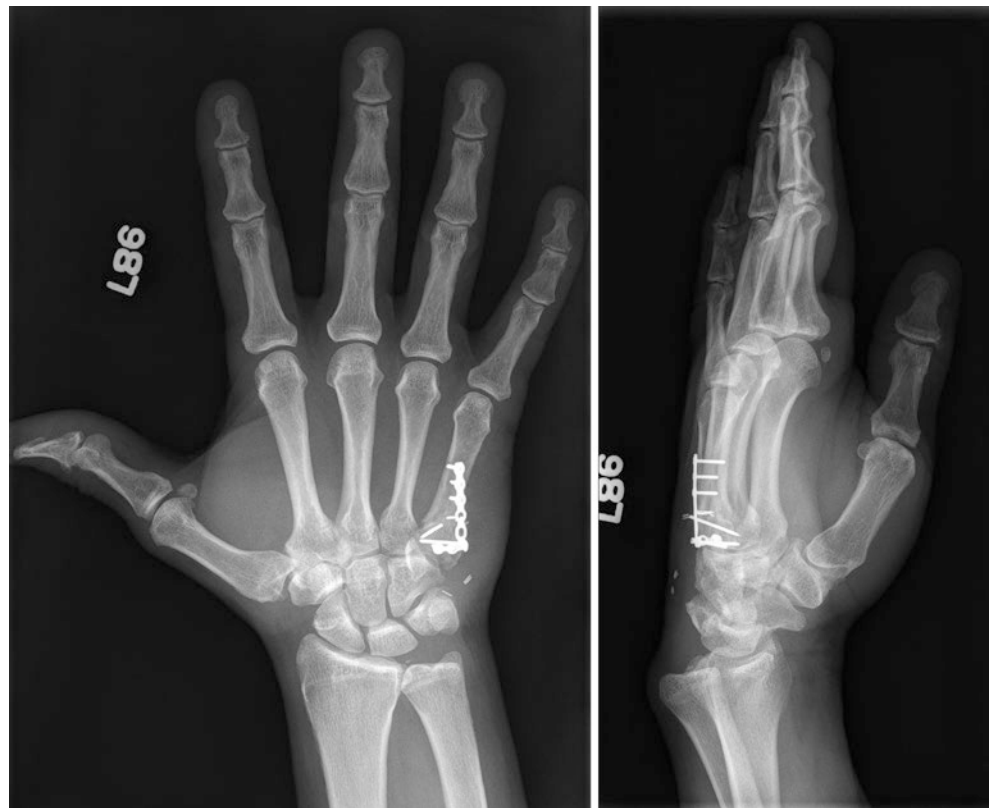
proximal, dorsal, and ulnar. Unlike injuries to the thumb, I have found that percutaneous fixation is less successful for these small base fractures and dislocations, so I frequently use ORIF in this area (Figs. 26.69, 26.70, and 26.71).



**Fig. 26.69** Injury radiographs of left small CMC with extensor carpi ulnaris (ECU) fragment (*arrow*)



**Fig. 26.70** Intraoperative radiographs demonstrating marked comminution and provisional fixation during ORIF



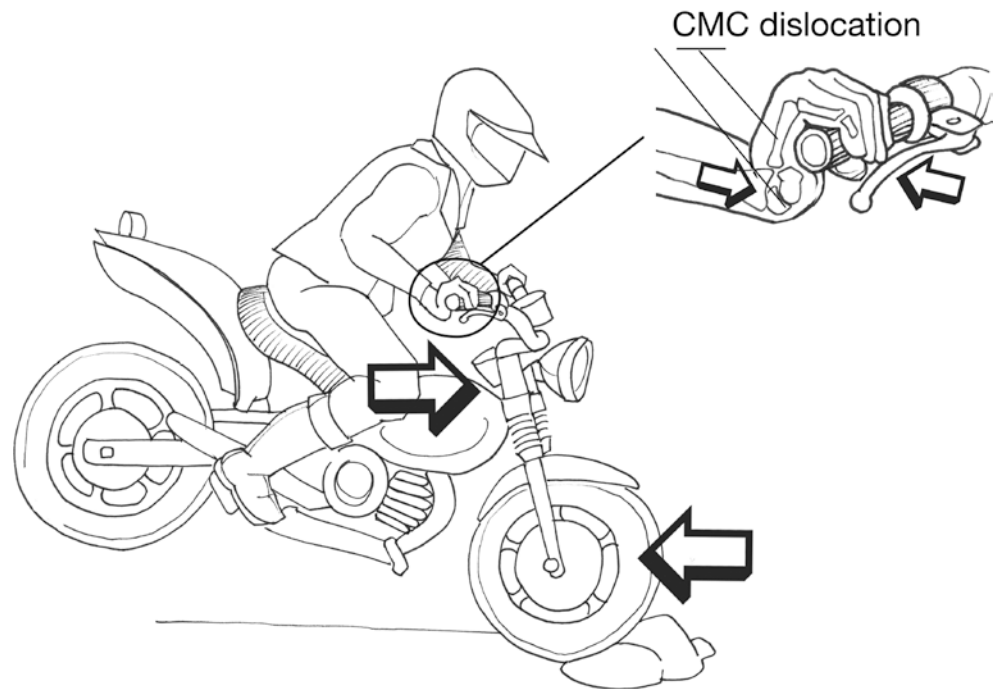
**Fig. 26.71** Radiographs on follow-up at time of discharge

## 26.7 Multiple Carpometacarpal Fracture Dislocations

Numerous papers have been published discussing multiple carpometacarpal joint fracture dislocations affecting the index, long, ring, and small fingers [15–17]. These multiple carpo-

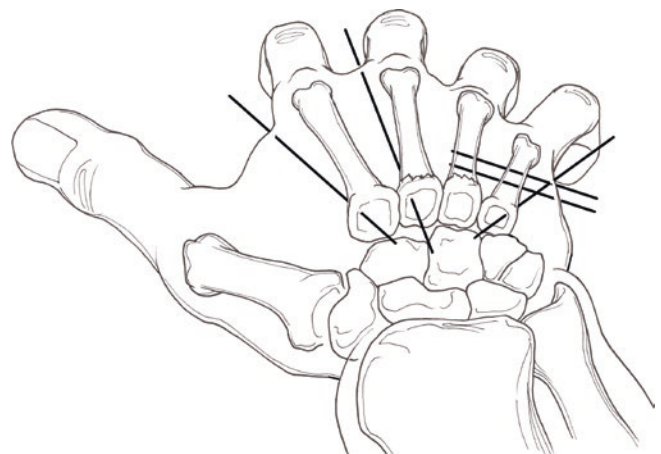
metacarpal fracture dislocations commonly occur in motorcycle accidents. The sudden deceleration is associated with the forward motion of the wrist and forearm while the driver's hands are still attached to the handlebars. The carpus and forearms are driven under the handlebars with the wrist in an extended position, causing the fracture dislocations (Fig. 26.72).

**Fig. 26.72** Mechanism of CMC fracture dislocations associated with a motorcycle accident



The take-home message from the reports is that dual incisions can be performed between the index and long and the ring and small, with direct joint visualization. Fixation in the less comminuted injuries is done in an in/out fashion through the bases, exiting distally, with the reduction being performed from the more stable side, from the index over to the small fingers, and then antegrade advancement of the K-wires

(Figs. 26.73, 26.74, 26.75, 26.76, 26.77, 26.78, 26.79, 26.80, 26.81, 26.82, 26.83, 26.84, and 26.85). Good results can be obtained with these injuries, but it can be a rather laborious process, as the K-wires are almost always in an untenable position exiting distally, and the patients tend to avoid finger range of motion. The K-wires remain in place for about 4–6 weeks.



**Fig. 26.73** Prepositioning K-wires through the dislocated bases prior to reduction and fixation across the CMCs



**Fig. 26.74** Injury radiographs demonstrating multiple dorsal CMC fracture dislocation in the left wrist secondary to an ATV accident



**Fig. 26.75** Radiographs of injury to opposite wrist: transscaphoid perilunate dislocation





**Fig. 26.76** Radiographs following ORIF with multiple K-wires placed in antegrade followed by retrograde insertion



**Fig. 26.77** Final radiographs following K-wire removal



**Fig. 26.78** Injury radiographs documenting dorsal dislocation at ring and small CMC joints and long metacarpal base fracture



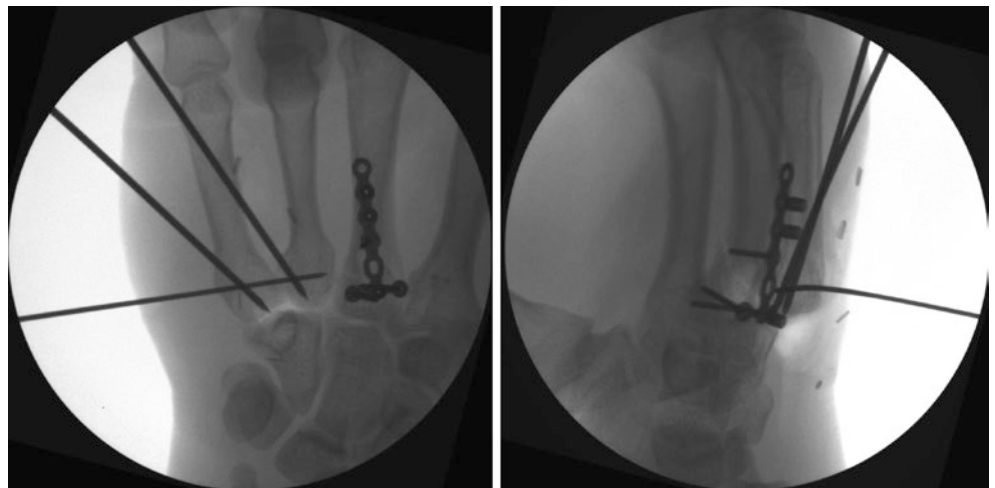
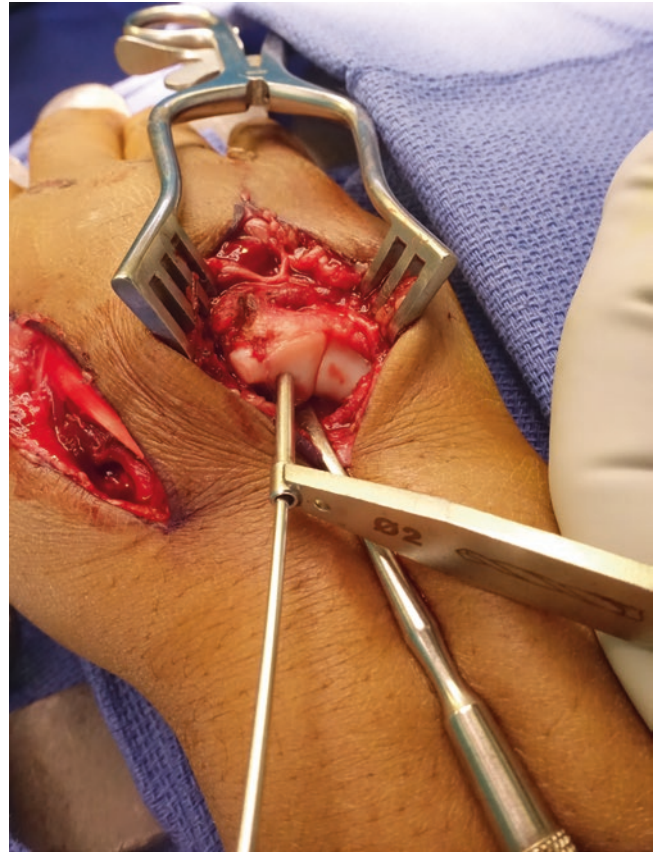
**Fig. 26.79** Incisions outlined for approach to CMC joints



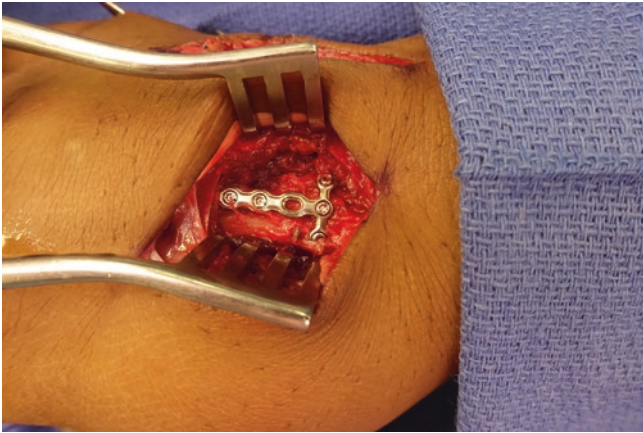
**Fig. 26.80** Dislocated ring and small CMCs



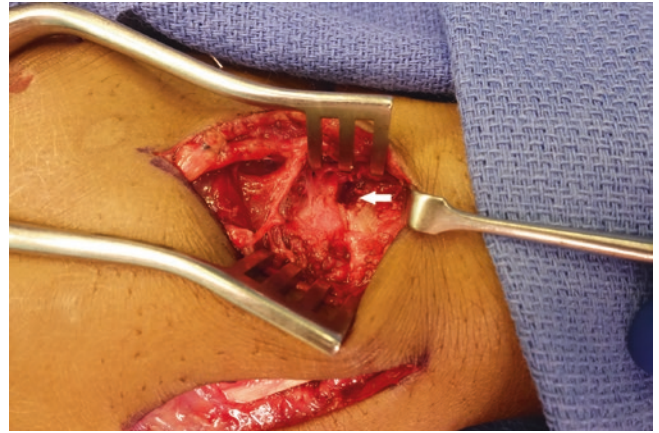
**Fig. 26.81** Inserting 0.0625-in. K-wires into the base of the ring metacarpal, to be followed by a small K-wire and then a transverse 0.045-in. K-wire



**Fig. 26.82** AP and lateral radiographs of right hand with preliminary K-wire fixation prior to CMC reduction



**Fig. 26.83** Fixation of long metacarpal base fracture with 1.5-mm mini locking plate



**Fig. 26.84** Reduced ring and small CMCs with dorsal rim defect in hamate (arrow)



**Fig. 26.85** Radiographs following reduction and K-wire fixation

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## 27.1 Biomechanical Parameters of Metacarpal Fractures

Residents and fellows frequently ask for dogmatic criteria regarding acceptable amounts of shortening, angulation, and rotation of metacarpal shaft and neck fractures. I've often heard 5 mm given for shortening; 5°, 10°, 15°, and 20° for angulation of index, long, ring, and small shaft fractures; 10°, 20°, 30°, and 40° for angulation of neck fractures; and no malrotation. The origin of these numbers is difficult to find, and the rationale and biomechanics behind some of these recommendations is scant at best. PubMed recently listed almost 1300 citations for "metacarpal," but only about 100 were shaft-focused and very few concentrated on the biomechanical aspects of shaft fractures. Can a review of the few studies pertinent to shortening, angulation, and rotation give any guidance towards clinical treatment? One confounding issue is that studies focus on isolated metacarpals and the impact of and on the adjacent intact metacarpal and finger may not reflect the actual clinical results.

### 27.1.1 Shortening

Metacarpal shortening can have an impact on hand function because of the consequences relative to the effective lengthening of the musculotendinous unit and the weakening of the extrinsic and intrinsic muscles. Deficits or limitations also can arise because of the potential quadriga effect of both the compromised isolated flexor and extensor systems. The restriction of motion of one tendon will have negative impact on the other tendons to which it is attached, as generally the finger does not work in isolation.

Wills *et al.* [1] recommended 5 mm as the tolerable limit of shortening, using a cadaver index finger model with shortening and testing digital forces in sequential finger flexion. Gerbino *et al.* [2] utilized an external fixation device and shortened metacarpals in 2-mm increments. Using a fluid pressure couple and a manometer, pressure declination was

greater for the index and middle fingers with 5 mm of shortening, with 10 mm of shortening having an additional impact on the ring finger. Strauch *et al.* [3] studied nine cadaver hands using the index and small metacarpal and an external fixator. The osteotomized metacarpals were shortened at 2-mm increments and loaded with a free-weight loading system. For every 2 mm of shortening, 7° of extensor lag occurred.

The intrinsics have a significant role in both grip and pinch strength. Meunier *et al.* [4] found dorsal intrinsic muscle architectural changes on metacarpal shortening such that the fiber length of the third dorsal interosseous increased and pennate angle decreased with subsequent ring metacarpal shortening. The authors correlated a 2-mm shortening with an 8% power loss; at 10 mm of shortening, the power loss was 45%. Another way to appreciate the impact of the intrinsics on strength is by paralyzing the muscles with a nerve block. Blocking the ulnar nerve at the wrist results in a 38% decrease in grip and a 77% decrease in pinch strength [5]. The critical point at which the intrinsics become dysfunctional from a metacarpal shortening standpoint is difficult to quantitate, however.

Low *et al.* [6] studied index and small metacarpals using a ratio system of baseline force for digital flexion and extension on both angulation and shortening. The force to attain full extension and flexion was utilized to develop a force ratio using the intact metacarpal extensor forces as a denominator, and angulation or shortening forces as a numerator. Thus, a force ratio was developed. The critical point of significant clinical shortening is difficult to pinpoint; it depends on the finger and metacarpal length and ranges from 3 to 10 mm.

The amount of shortening of loaded osteotomized metacarpals has also been studied. Eglseider *et al.* [7] determined that the ring metacarpal shortened 2.1 mm with the intermetacarpal ligament intact, and 5.8 mm after sectioning. Strauch *et al.* [3] found 5 mm of shortening in the index and small metacarpals with intact deep transverse intermetacarpal ligaments, with the intermetacarpal and deep transverse intermetacarpal ligaments being the same structure (Table 27.1).

**Table 27.1** Metacarpal shortening findings

Author	Year	Shortening	Result
Strauch et al. [3]	1998	2 mm	7° extensor lag per increment
Wills et al. [1]	2013	Digital flexion force: significant changes with finger position:	
		• Full digital extension	No change regardless of shortening
		• 50% aggregate flexion	≥7.5 mm shortening
Low et al. [6]	1995	• Full digital flexion	5.0 mm shortening
		>3 mm	Flexion and extension forces decreased significantly
Gerbino et al. [2]	1993	1 cm	Pressure reduction by 14.5–18.5 mm Hg via pressure transducer
			2 cm fingertip pulp to palm, with 1 cm of metacarpal shortening
Meunier et al. [4]	2004	Interosseous muscle impact plateaus at 8 mm:	
		• 2 mm	92% optimal power production
		• 10 mm	55% optimal power production
Eglseder et al. [7]	1997	Ring metacarpal shortening following osteotomy:	
		• Intact intermetacarpal ligament	2.1 mm shortening
		• Section ligament	5.8 mm shortening

### 27.1.2 Angulation

The impact of angulation with flexor and extensor tendons has been evaluated using metacarpal neck models, but translating these findings to the shaft may not be valid. There is a difference on the impact on moment arm changes at the head

relative to the shaft: the head can rotate around the flexion and extension axis and does not effectively tighten the extensors, as would be the case with the shaft and associated apex dorsal angulation in the fracture setting.

Angulation was studied by Low *et al.* [6] using a force ratio. They found that with pure rotation, the flexor forces decreased and extensor forces increased when 30° of apex dorsal angulation occurred. The difficulty in judging angulation alone clinically is that angulation and shortening will occur together. Pereira *et al.* [8], in a follow-up study to their work on shortening, found that with dorsal angulation, the extensor tendon force within the system increased and the flexor force decreased, but with shortening and angulation, both the extensor and flexor forces decreased (Table 27.2). The finding of increased extensor force with angulation can be understood because angulation increases the tension within the viscoelastic properties of the musculotendinous system.

How much shortening and angulation are significant? This appears to occur at 2 mm of shortening with 40° of dorsal apex angulation. Clear angulation limits are difficult to define from the biomechanical findings but appear to be about 30°–40° apex dorsal. The index and long fingers tolerate less because of their constrained bases, whereas the ring and small fingers are more tolerant because of their more mobile carpometacarpal joints.

**Table 27.2** Effects of angulation and shortening on flexor and extensor muscle forces

Muscle forces	Shortening, mm	Dorsal angulation, degrees
Mean flexion ratio, significant	0, 1.0, 2.0	0
	0, 1.0, 2.0	10
	0, 1.0, 2.0	20
Mean extension ratio, significant	0.0	30
	1.0	30
	2.0	40
	3.0	50
	4.0	50
	5.0	60

From Pereira *et al.* [8]

### 27.1.3 Rotation

Rotation of the metacarpal can have a much more profound effect with small degrees of malalignment that result in digital overlap. From a biomechanical viewpoint, only one article discusses metacarpal rotation with finger deviation and overlap. Manktelow and Mahoney [9] stated that 10° of rotation may result in 2 cm of lateral finger deviation (2 mm of overlap for each 1° of rotation). In their report, 1 mm of metacarpal osteotomy wedge resection resulted in 8.6 millimeters of fingertip deviation. These authors found the impact of rotation limitation by the intermetacarpal ligament to be nonhindering, but the study of correctional osteotomies by Gross and Gelberman [10] found it limiting. Using a clinical measurement of the plane of the nail relative to the horizontal surface, Royle [11] considered rotational deformity more than 10° to be clinically significant, requiring intervention, but did not note how that correlated to metacarpal malrotation.

Opgrande and Westphal [12] stated in a section on treatment of metacarpal fractures that each degree of rotation of the shaft results in 5° of tip rotation and clinical digital overlap, but the source of this statement is not clear. The difficulty with a clinical correlation and acceptable limits is the inability to measure rotation radiographically (unlike shortening and angulation). Therefore, we are left with the clinical examination of digital overlap more than direct measurement of the metacarpal rotation. Rotation should not be accepted, and fortunately, the inboard metacarpals are stabilized by the deep intermetacarpal ligament, assisting in the prevention of rotation.

### 27.1.4 Recommendations

Putting together the three facets—shortening, angulation, and rotation—it is difficult to generalize any recommendation because each metacarpal is unique and yet affects the overall hand function. Simplifying and generalizing, however, 5–6 mm of shortening may be considered clinically critical, and 30° of angulation may be concerning. Rotation should not be accepted. In summary, these biomechanical parameters need to be acknowledged, but historical and personal guidelines will probably dictate your treatment.

## 27.2 Treatment Options

The treatment algorithm for metacarpal fractures runs the spectrum of nonoperative closed reduction and splinting, external fixation, K-wire fixation, and open reduction internal fixation (ORIF). But particularly in a trauma setting, the decision-making process is also driven by the multiplicity of injuries sustained by patients. Sometimes, hand fractures that would be treated nonoperatively in isolation will be stabilized to allow the hand to be utilized for monitoring, IV access, and arterial lines.

The options for metacarpal fixation use various techniques that are not unique to a particular metacarpal. The treatment of the thumb will be reviewed first, and then the index, long, ring, and small fingers will be grouped together. Patient positioning for metacarpal fracture fixation is supine with the hand table at the center of the shoulder and use of a nonsterile tourniquet. A review of positioning, prepping, and draping is presented in Chap. 21.

### 27.2.1 Metacarpal Fractures of the Thumb

The inherent mobility of the thumb carpometacarpal joint allows a large degree of malalignment in the shaft to be well tolerated. Green and O'Brien [13] reviewed fractures of the thumb metacarpal and did not give an exact angulation to be tolerated, but radiographically, their example demonstrated a patient with about 35° of apex dorsal angulation, who was projected to have a successful outcome. In a way, thumb metacarpal fractures are similar to Bennett's fractures in the sense that the forces creating the displacement are the same. Particularly if there is a degree of obliquity, the long flexors and extensors can have a proximally displacing force while the adductor tends to displace the distal shaft ulnarly.

Transverse fractures at the metadiaphyseal region are amenable to closed treatment and splinting. Short oblique fractures can be addressed with closed reduction and percutaneous K-wire fixation. Longitudinal K-wires can be utilized. However, if there is any comminution or obliquity, there can be the tendency for rotation and shortening (Figs. 27.1, 27.2, and 27.3).





**Fig. 27.1** Presentation radiographs in splint, demonstrating shortening and loss of reduction in splint



**Fig. 27.2** Before K-wire removal following percutaneous fixation



**Fig. 27.3** Radiographs on discharge following K-wire removal

When K-wires are utilized percutaneously, as in Figs. 27.1, 27.2, and 27.3, I tend to leave them in place for about 6 weeks. Longitudinal K-wires placed through the

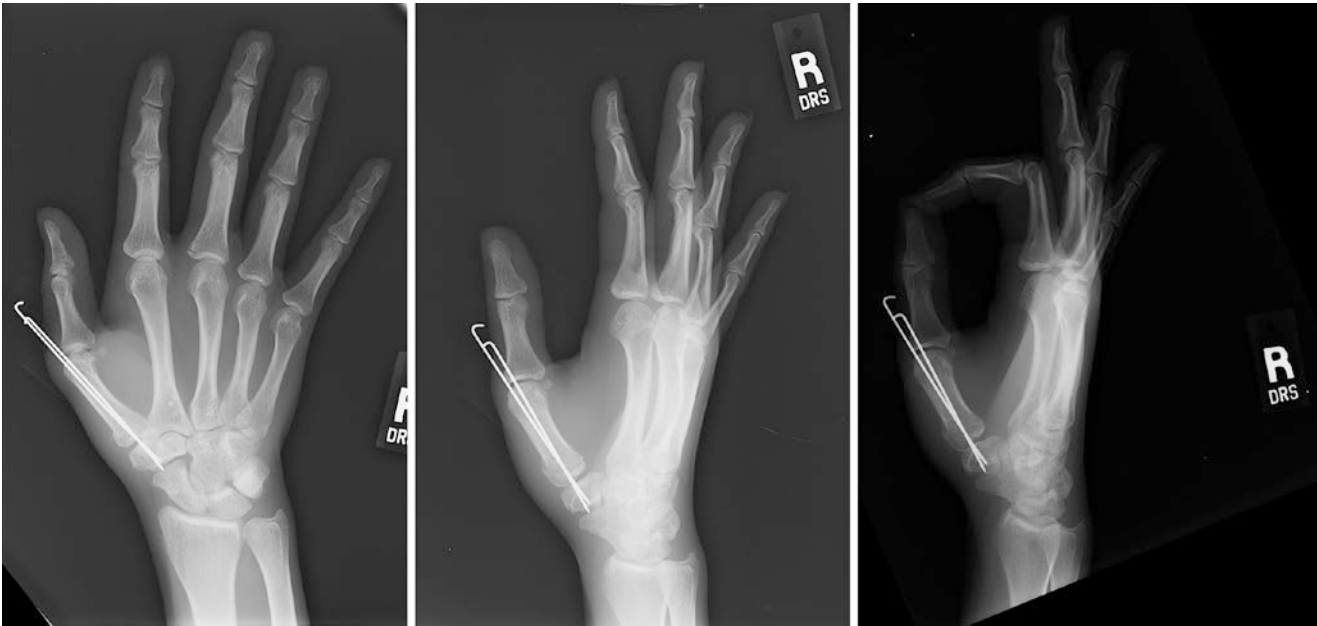
metacarpal head are removed after 3–4 weeks because of the possibility of metacarpophalangeal (MCP) joint stiffness and septic arthritis (Figs. 27.4, 27.5, and 27.6).



**Fig. 27.4** Injury radiographs demonstrating metadiaphyseal fracture transverse and less amenable to a radial start point for the K-wire



**Fig. 27.5** Longitudinal K-wire fixation



**Fig. 27.6** Before K-wire removal

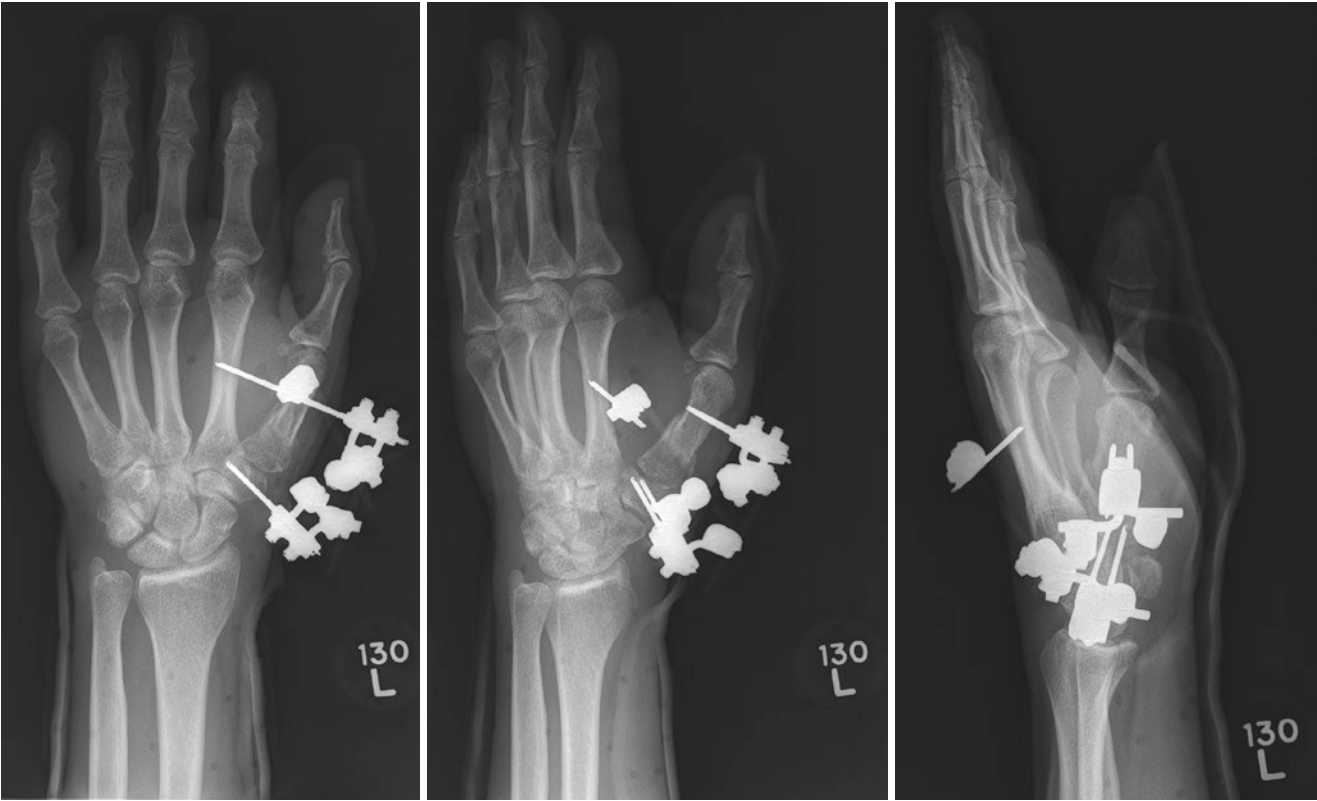
External fixation is also effective for unstable shaft fractures, which could be treated with ORIF but will heal nicely if you just maintain length (Figs. 27.7, 27.8, 27.9, and 27.10).



**Fig. 27.7** Injury radiographs



**Fig. 27.8** Traction radiographs demonstrating reducibility



**Fig. 27.9** External fixation using triangular frame construct



**Fig. 27.10** Radiographs following external fixator removal



ORIF is performed from a dorsal approach, splitting the extensor pollicis brevis and extensor pollicis longus, with attention to the sensory nerves. Various plates can be used,

including 1.5-mm or 2.0-mm nonlocking or locking plates if metaphyseal fixation proximally or distally is required (Fig. 27.11).



**Fig. 27.11** (a) Injury radiographs of thumb base metadiaphyseal fracture. (b) Healed fracture following open reduction internal fixation (ORIF)

### 27.2.2 Metacarpal Fractures of the Other Fingers

Many index, long, ring, and small metacarpal fractures can be treated nonoperatively; this is particularly true of the ring

metacarpal, which is suspended from the long and small metacarpals and will shorten only a limited amount because of the intermetacarpal ligaments (Figs. 27.12 and 27.13).

The caveat is that rotation must be corrected, which can be performed by restraining the ring finger to the long and

**Fig. 27.12** Initial radiographs of a ring metacarpal fracture following the patient's initial complaints of hand pain from an injury 6 weeks prior; callus not seen



**Fig. 27.13** Discharge radiographs. No complaints, full range of motion, no rotation or deformity



small fingers or using outriggers in the cast or splint. An ulnar gutter splint also can be utilized.

Frequently, metacarpal fractures—particularly of the outboard index and ring fingers—have obliquity and tend to shorten. I have occasionally performed percutaneous fixation, but I find this more difficult than one would believe at first pass. I love to hear the residents tell the staff that we're going to run up to the OR and do a quick percutaneous pinning, when in fact, ORIF would probably be faster. The issue

relative to percutaneous pinning is getting acceptable reduction with length restoration and angulation correction. Even more problematic is rotation, followed by the ability to hit the metacarpals. When addressing the long and the ring fingers, the arch needs to be flattened. It can be difficult to successfully obtain a three-metacarpal purchase. This technique is used more commonly in proximal and distal fractures as opposed to shaft fractures (Figs. 27.14, 27.15, 27.16, 27.17, 27.18, 27.19, and 27.20).



**Fig. 27.14** Injury radiographs metacarpal base fractures of the left ring and small fingers



**Fig. 27.15** Radiographs following closed reduction with percutaneous fixation. The patient's medical condition precluded more extensive intervention

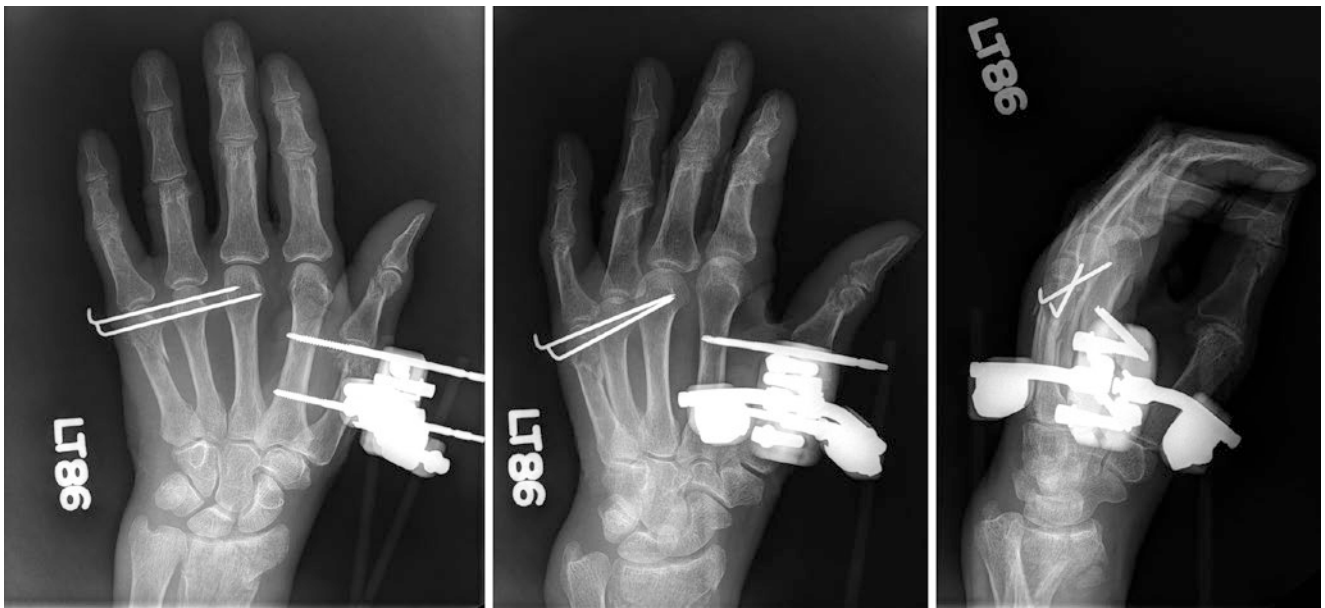


**Fig. 27.16** Injury radiographs of right small carpometacarpal base fracture

**Fig. 27.17** Radiographs following reduction with the transverse K-wire to suspend the small metacarpal



**Fig. 27.18** Injury radiographs of left wrist and hand in a hemodynamically unstable patient



**Fig. 27.19** Radiographs following reduction and percutaneous fixation



**Fig. 27.20** Final radiographs at time of discharge



When ORIF is selected, I use a straight incision over the metacarpal to be approached and try to avoid dividing the juncturae (which is not always possible). I will occasionally perform just lag screws for oblique fractures [14], but I rarely use just lag screws on the index and small border digits because I am concerned about the potential of torquing

forces that could result in fracturing through the drill holes [15]. The obliquity should be two and a half times the diameter so that two to three screws can be inserted [16]. The principle harks back to the thirds principle of lag screwing and the amount of bone needed around the screws (Figs. 27.21 and 27.22).

**Fig. 27.21 (a, b)**  
Presentation radiographs in  
splint of long and ring  
metacarpal fractures





**Fig. 27.22** Radiographs at time of discharge

It has been reported, however, that one lag screw is superior to a dorsal plate in certain modes of testing [17]. Another report found over-drilling unnecessary when using a compression device, allowing for bicortical fixation, thus decreasing steps and the potential for near-cortex complications

when over-drilling [18, 19]. Finally, you may go to the OR with the intent of lag screw fixation, when in fact one of the spikes is a butterfly, obviating the ability to adequately perform lag screw fixation (Figs. 27.23 and 27.24).



**Fig. 27.23** Injury radiographs demonstrating long oblique fractures that are really butterfly fragments that require plate fixation, not lag screw



**Fig. 27.24** Radiographs of healed fractures following ORIF

When using plate fixation, I try to have four cortices—that is, two bicortical screws, on either side of the fracture—but noting work that has shown unicortical screws to be effective [20, 21]. I have also found soft tissue coverage over the plates after fixation can be difficult, as the interossei do

not approximate well. ORIF with plates follows the guidelines of fracture preparation, reduction, anatomic alignment, and fixation. Plate size and length is driven by metacarpal size, bone quality, and fracture length.



Metacarpal fixation may require a combination of techniques (Figs. 27.25, 27.26, 27.27, 27.28, 27.29, 27.30, 27.31, and 27.32). As you venture further out in the metacarpals,

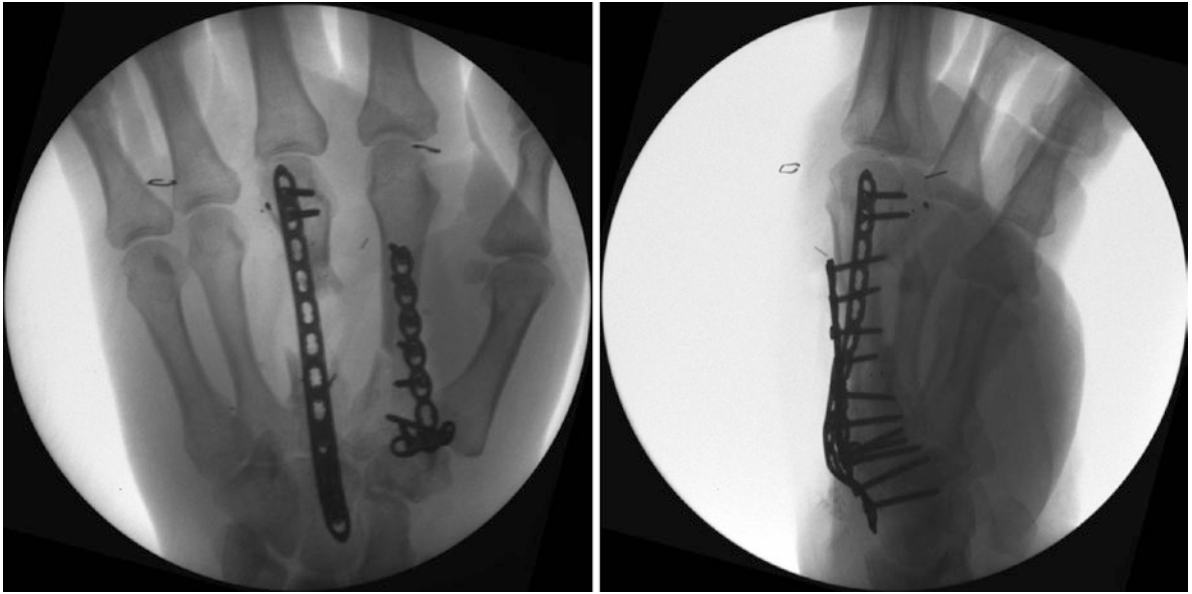
neck, head, and metacarpal phalangeal joint region, the treatment options are somewhat increased. Additional options include arthroplasty and fusion.



**Fig. 27.25** Radiographs of left hand revealing index and long metacarpal fractures



**Fig. 27.26** Intraoperative C-arm view of right hand for metacarpal length determination



**Fig. 27.27** (a, b) Intraoperative radiograph following ORIF prior to distal radius bone grafting



**Fig. 27.28** Follow-up radiographs demonstrating union of both metacarpals, prior to possible tenolysis

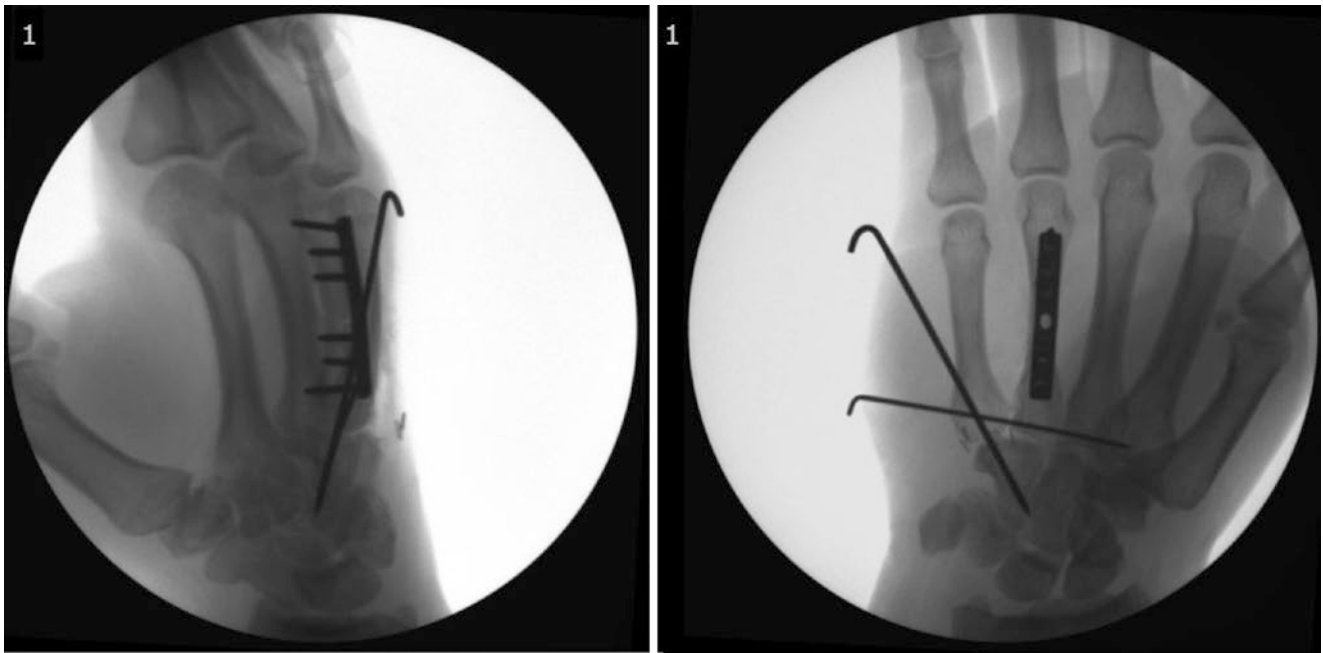


**Fig. 27.29** Injury radiographs demonstrating ring metacarpal fracture and dorsal avulsion of hamate



**Fig. 27.30** Intra-operative fixation radiographs





**Fig. 27.31** Intra-operative fixation radiographs

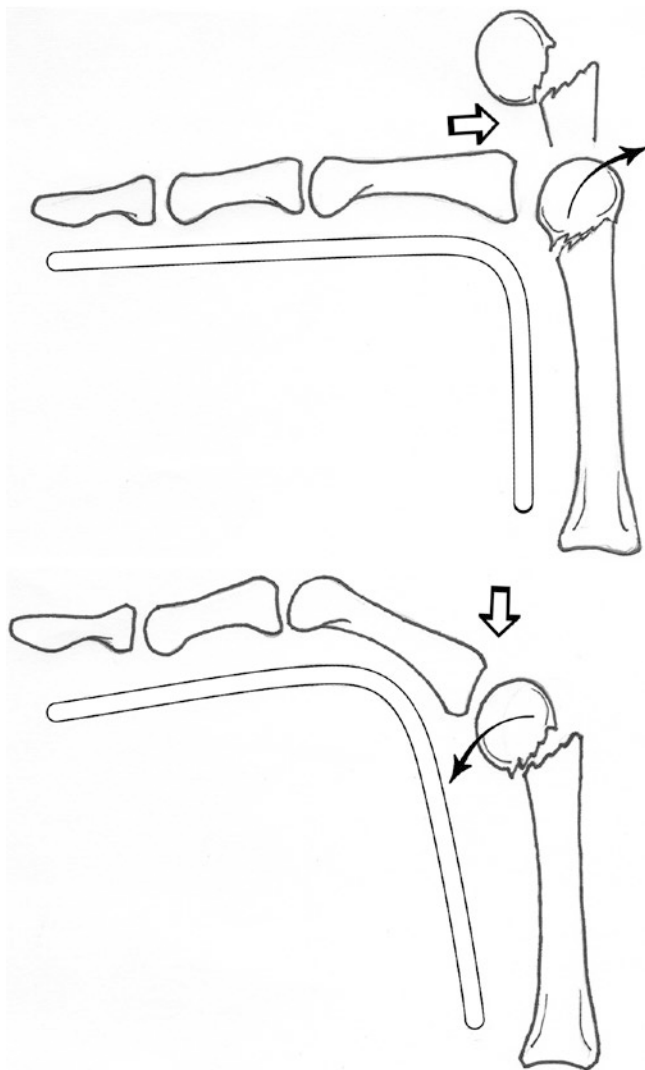


**Fig. 27.32** Final radiographs at time of discharge

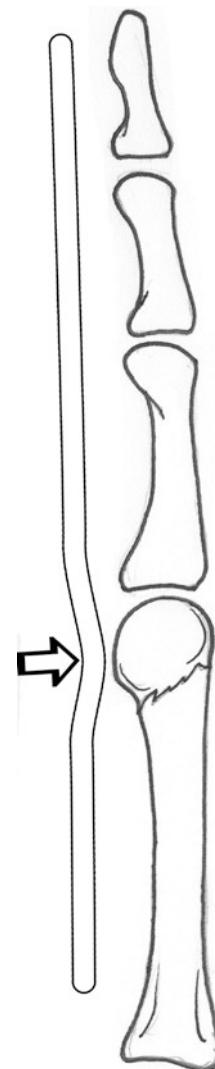
Before discussing closed treatment, the amount of angulation that can be tolerated at the neck level needs to be considered at the neck level and is still difficult to nail down. Hunter and Cowen [22], in an interesting paper relative to a Workman's Compensation group in Philadelphia, looked at fractures of the small metacarpal shaft and neck. Reduction was performed if on presentation the angulation was greater than  $40^\circ$ , with the notation that it was not uncommon to accept  $70^\circ$  of angulation of the metacarpal neck. Not only does this reflect the difficulty in establishing a firm degree of angulation accepted, it is also very difficult to measure angulation even on a dedicated lateral radiograph of the small finger. Ali *et al.* [23] recommended accepting only up to  $30^\circ$  of small metacarpal neck angula-

tion because of the impact on intrinsic weakening and function with projected strength declination above  $30^\circ$ . Birndorf *et al.* [24] also supported a  $30^\circ$  maximum angulation of metacarpal neck fractures.

If the decision is made to treat a metacarpal neck fracture nonoperatively and a reduction maneuver must be performed, I suggest that the 90 and 90 reduction technique so frequently cited should be abandoned. The reason for this is that, despite the best intentions of flexing the MCP joint and having the proximal interphalangeal (PIP) joint in extension, when applying the splint, the reduction maneuver actually winds up aggravating the metacarpal neck fracture angulation and having the PIPs flexed (Figs. 27.33, 27.34, 27.35, 27.36, 27.37, and 27.38).



**Fig. 27.33** Top: Desired and theoretical reduction of rotated metacarpal head. Bottom: Frequent resultant splinting finger positioning, aggravating metacarpal head rotation



**Fig. 27.34** Longitudinal splint with reduction of rotated metacarpal head



**Fig. 27.35** Injury radiographs of small metacarpal shaft



**Fig. 27.36** Splinting radiographs demonstrating the metacarpophalangeal joint (MCP) in extension as opposed to flexion; note 30° of proximal interphalangeal joint (PIP) flexion





**Fig. 27.37** Injury radiographs of right ring and small metacarpal neck fractures



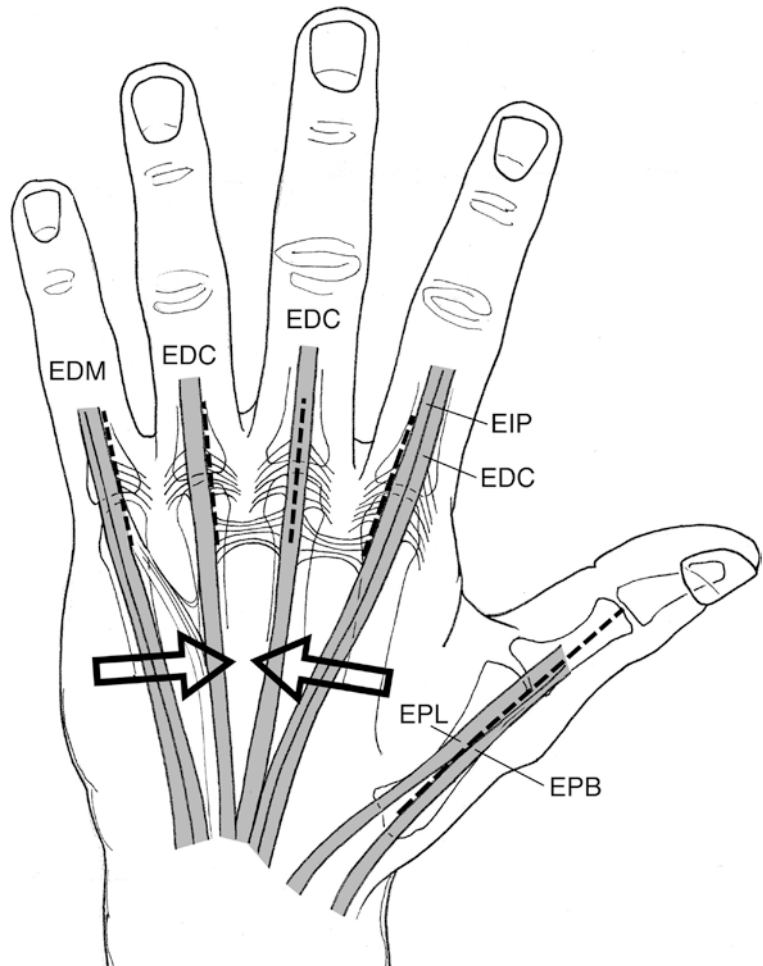
**Fig. 27.38** Radiographs following splinting extension with reduction of the small metacarpal fracture

The admonition that the MCP joint should be in flexion to prevent stiffness is certainly one to respect, but the 3–4 weeks that it may be in an extended position is certainly well tolerated [25, 26]. I use an ulnar gutter splint with the MCPs and PIPs in extension, and apply direct palmar-to-dorsal pressure to actuate the reduction.

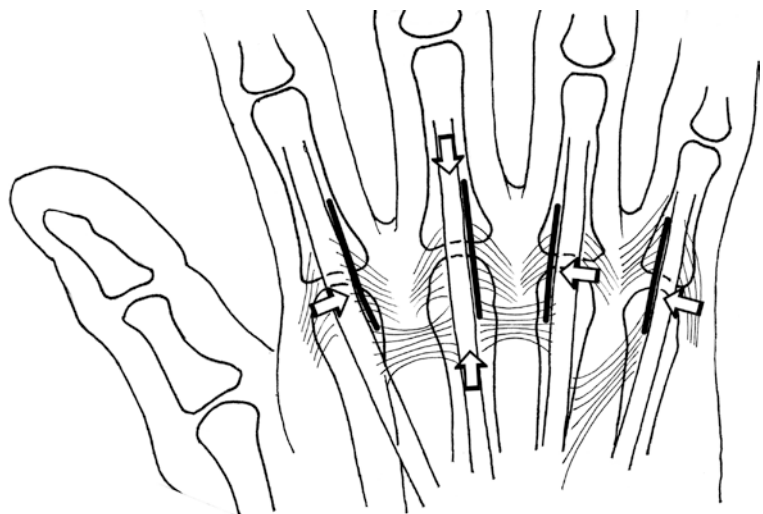
If the decision is made for ORIF, let's review the surgical incisions and approaches before demonstrating

particular techniques. As I've pointed out previously, one needs to think about the end of the operation at the beginning of the operation, and this is no more true than with the approach to the metacarpal neck and MCP joints. When MCP flexion and extension is undertaken, the extensors form a vector directed towards the midline (Figs. 27.39 and 27.40).

**Fig. 27.39** Midline vector of extensors during flexion and extension of finger



**Fig. 27.40** MCP incisions through sagittal bands and capsule



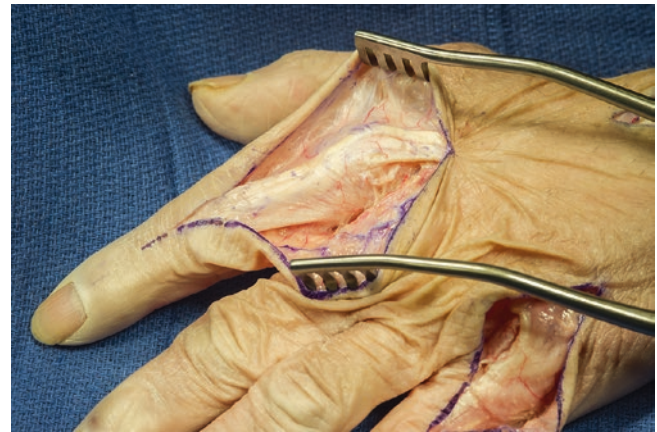


As such, the sagittal bands on the index finger will be tensioned radially, and ulnarly on the small. I approach the MCP joint to the index finger from the ulnar side, radially in the ring and small, and usually ulnarly for the long finger.

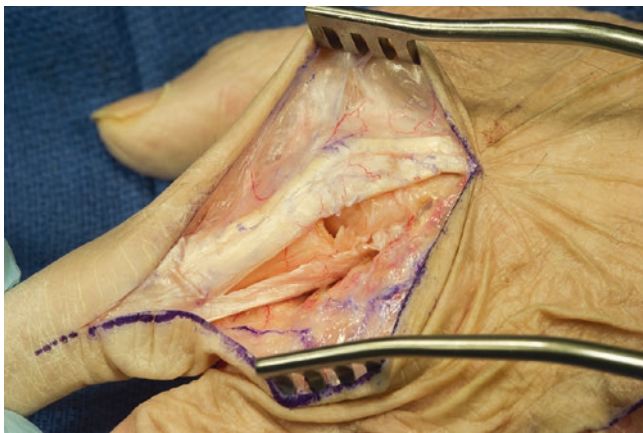
The sagittal band repair will be protected by the displacing force directed towards the repair side. Put another way, “The force is with you” (Figs. 27.41, 27.42, 27.43, 27.44, 27.45, 27.46, and 27.47).



**Fig. 27.41** Incisions for access to index and small metacarpal neck, head, and proximal phalanx



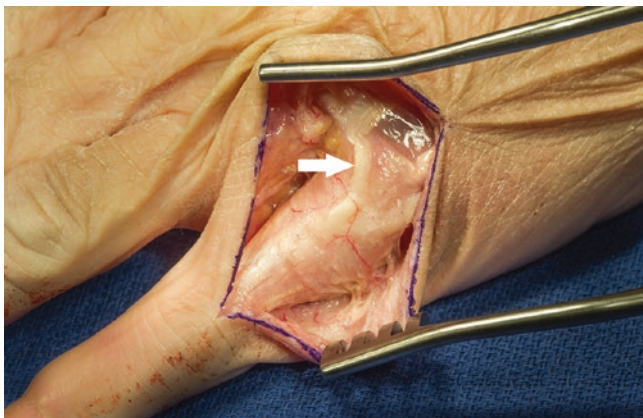
**Fig. 27.42** Index finger ulnar approach to MCP



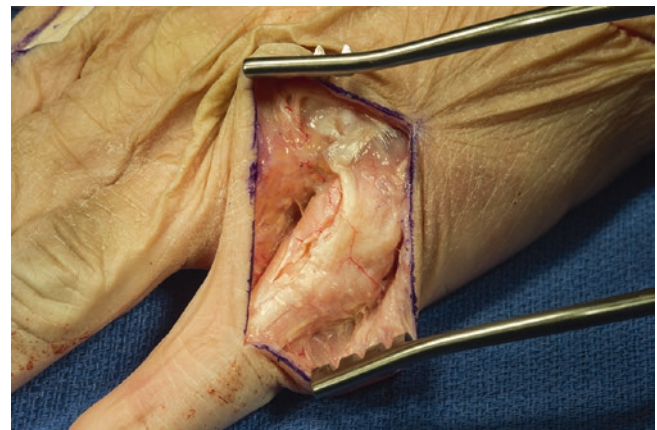
**Fig. 27.43** Incision ulnarly through the sagittal band and oblique fibers



**Fig. 27.44** MCP following capsulectomy



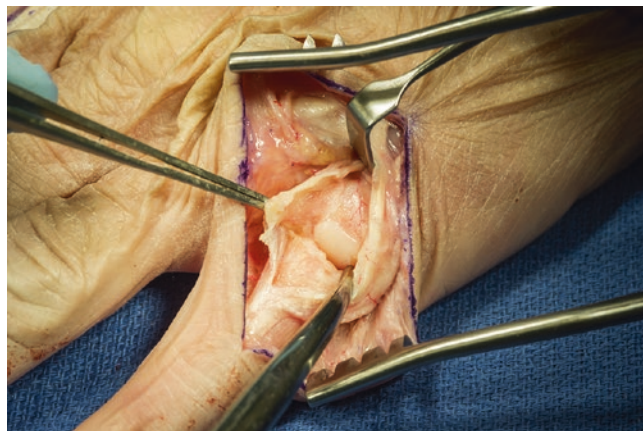
**Fig. 27.45** Small finger approach to MCP with juncturae tendinea to small finger extensor (arrow)



**Fig. 27.46** Incision in sagittal band and oblique fibers



**Fig. 27.47** Exposure of MCP following capsulectomy



ORIF of the neck and head fractures can be very difficult. I point out to patients that this is frequently a two-operation injury: one to put in the hardware and the second to perform

a capsulectomy (because of limited motion), as well as for hardware removal (Figs. 27.48, 27.49, 27.50, 27.51, 27.52, 27.53, and 27.54).



**Fig. 27.48** Injury radiographs with multiple metacarpal and phalangeal fractures



**Fig. 27.49** Postoperative radiographs following ORIF. Note slightly long K-wire in metacarpal head



**Fig. 27.50** Radiographs following MCP capsulectomy



**Fig. 27.51** Injury radiographs of right small metacarpal neck fracture



**Fig. 27.52** Attempt at splint; note PIP flexion and metacarpal head forced into flexion



**Fig. 27.53** This patient opted for ORIF



**Fig. 27.54** This patient opted for capsulectomy



I favor the K-wire and tension band wiring modality for head neck fractures without any good metaphyseal bone (Figs. 27.55 and 27.56), because there is a potential problem with plates dorsally. MCP joint flexion results in a palmar

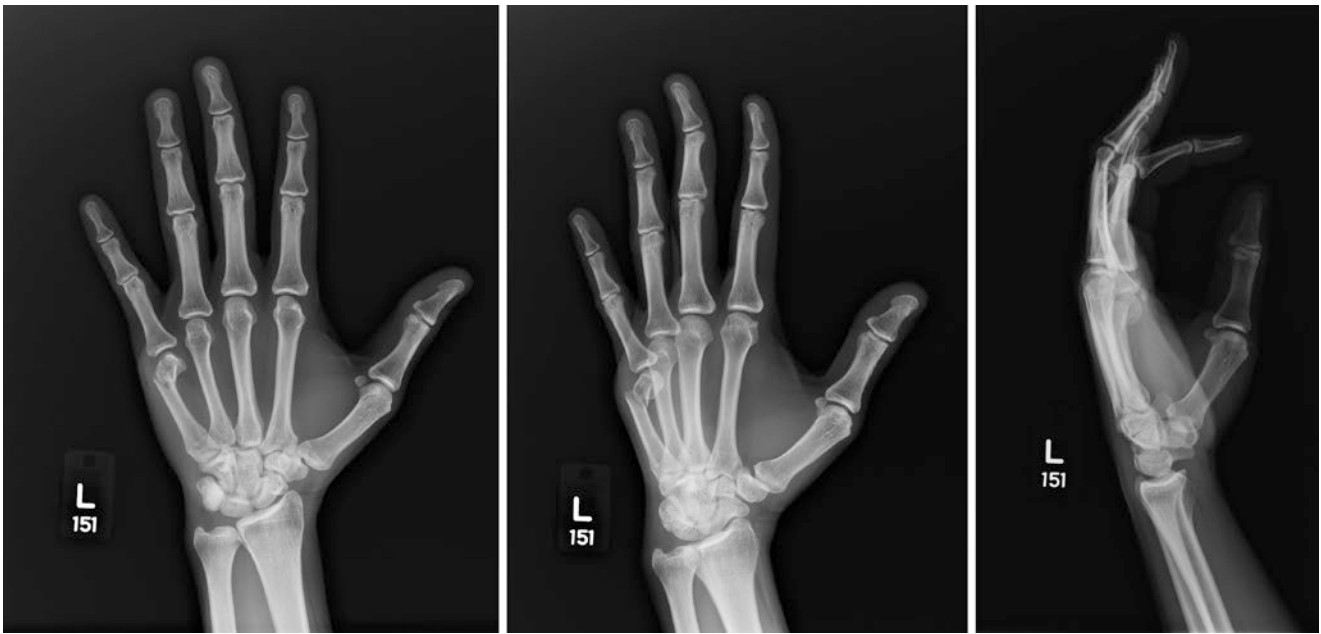
displacing force that could result in the metacarpal head being pulled off the screws in the plate. By using the K-wires and tension banding technique, the fixation actually counters this force (Figs. 27.57 and 27.58).

**Fig. 27.55** Injury radiograph of right index metacarpal neck fracture



**Fig. 27.56** Radiographs following fixation with tension band technique





**Fig. 27.57** Injury radiographs of left small metacarpal neck fracture with delayed presentation

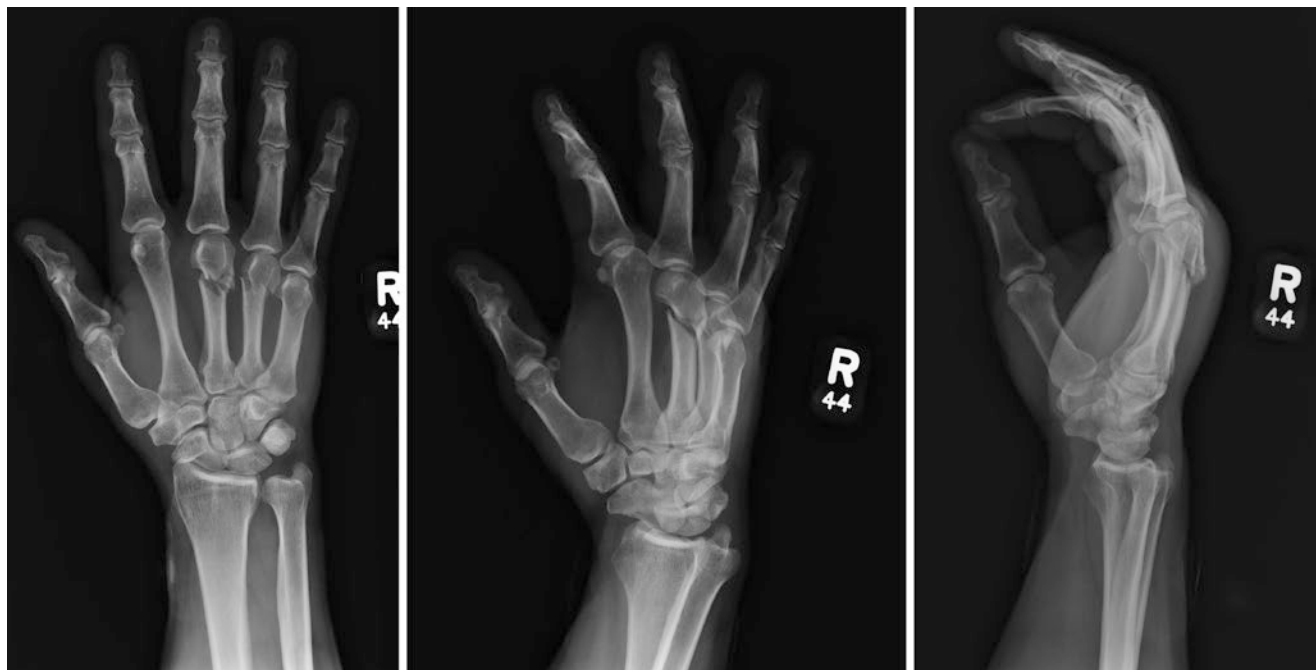


**Fig. 27.58** Radiograph following ORIF that included dorsal tension banding because of forces required to actuate reduction



I do use dorsal plates when there is some good cortical bone still attached to the head; the mini-locking 1.5-mm plates have been a nice addition to our armamentarium

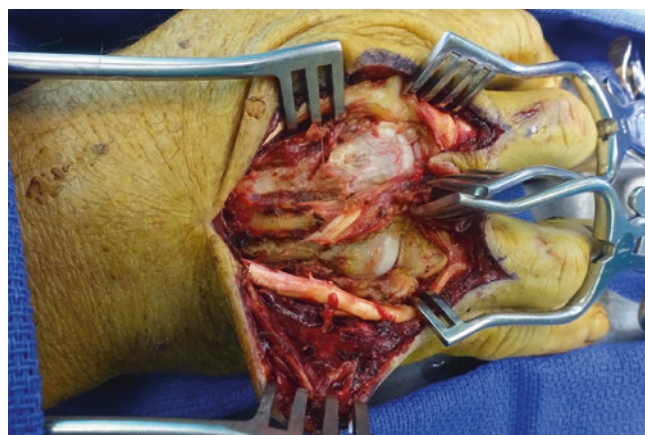
(Figs. 27.59, 27.60, 27.61, 27.62, 27.63, 27.64, 27.65, 27.66, 27.67, 27.68, 27.69, 27.70, 27.71, and 27.72).



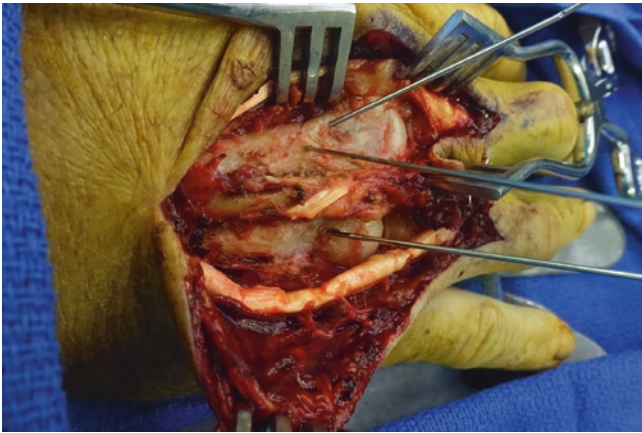
**Fig. 27.59** Injury radiographs of right hand with long and ring metacarpal neck fractures



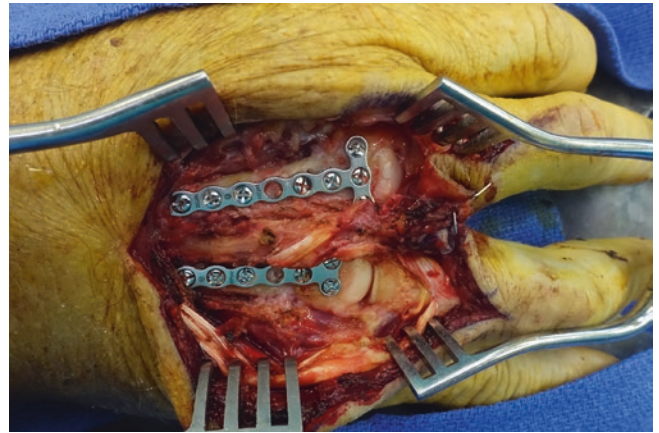
**Fig. 27.60** Incision for approach to long and ring metacarpal neck fractures



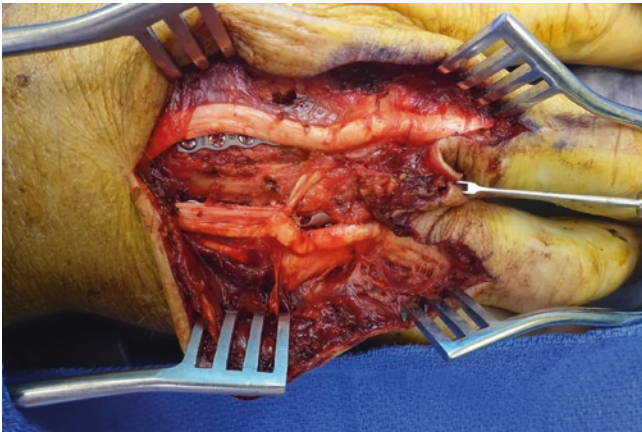
**Fig. 27.61** Neck fractures exposed, juncturae divided



**Fig. 27.62** Provisional K-wire fixation



**Fig. 27.63** Definitive fixation with 2.0-mm mini-fragment plates with adequate distal cortical purchase to obviate tension band technique



**Fig. 27.64** Closure with repair of juncturae



**Fig. 27.65** Intra-operative posteroanterior (PA), lateral, and anteroposterior (AP) radiographs of right hand following ORIF



**Fig. 27.66** Radiographs at time of discharge



**Fig. 27.67** Injury radiographs (PA projection) demonstrating ring metacarpal and small metacarpal neck fracture





**Fig. 27.68** Splinted radiographs

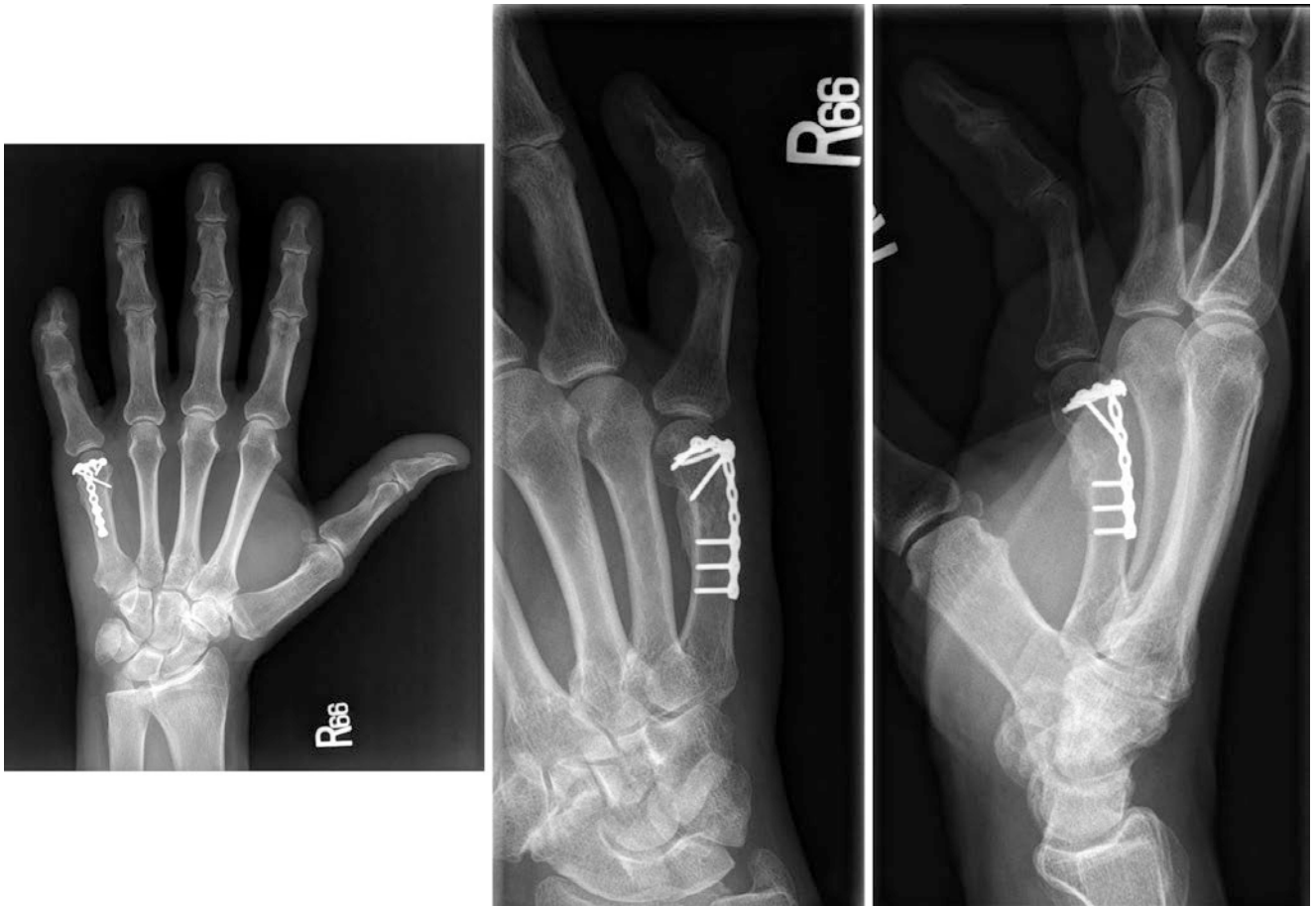


**Fig. 27.69** Injury radiographs, AP projection

**Fig. 27.70** Patient radiographs following ORIF; the patient opted for surgery



**Fig. 27.71** Injury radiographs of open small metacarpal neck fracture



**Fig. 27.72** Healed fracture at time of discharge



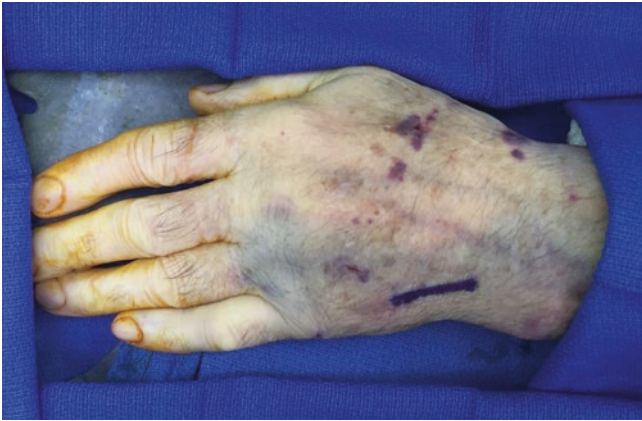
Another very nice technique, which is between ORIF and percutaneous fixation, is the bouquet technique (Figs. 27.73, 27.74, 27.75, 27.76, 27.77, 27.78, 27.79, and 27.80).



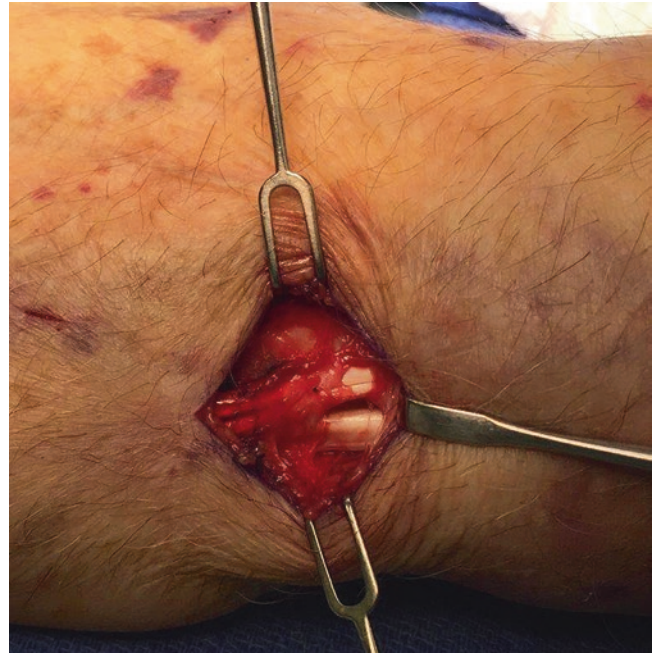
**Fig. 27.73** Fixation radiographs of small metacarpal, utilizing bouquet technique



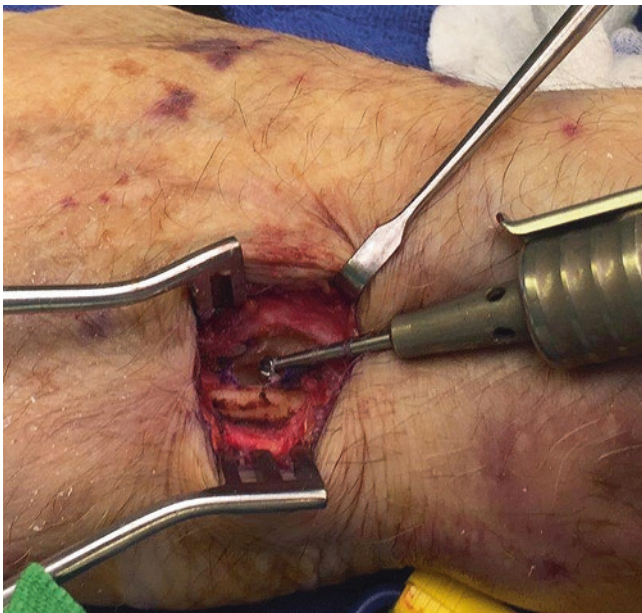
**Fig. 27.74** Injury radiographs demonstrating small metacarpal neck and distal radius fracture



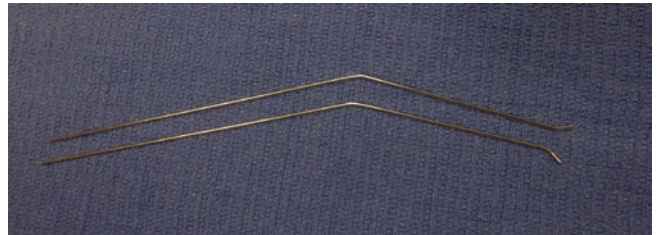
**Fig. 27.75** Incision for approach to base of small metacarpal



**Fig. 27.76** Extensor digiti minimi and extensor carpi ulnaris to be retracted ulnarly



**Fig. 27.77** Burr utilized along radial aspect of base to create an oval window, sloped to allow gliding insertion of K-wire



**Fig. 27.78** 0.045-in. K-wires cut and bent for intramedullary insertion



**Fig. 27.79** Intra-operative sequence of intramedullary K-wire insertion



**Fig. 27.80** Radiographs of healed metacarpal neck at time of discharge



I have not been using this technique a lot for shaft fractures, but it certainly is an option. Intramedullary fixation is carried out with longitudinal K-wire insertion at the base of the metacarpal. When I perform this technique, particularly on the small finger, I approach the insertion through the radial side to avoid a bony defect ulnarly; this is also where the extensor carpi ulnaris (ECU) inserts. I make an oval hole with a burr, angling to allow the K-wires to slide down

the slope of the opening into the metacarpal. The K-wires are bent such that there will be at least two with opposing angulations, which help control rotation. In an effort to control not only rotation, the length can be controlled by cutting the pins and tamping them into the access hole, thus preventing backing out.

I do use external fixation; it is commonly used as a staging procedure (Figs. 27.81, 27.82, and 27.83).



**Fig. 27.81** Injury radiographs following a gunshot wound (GSW) to left index MCP

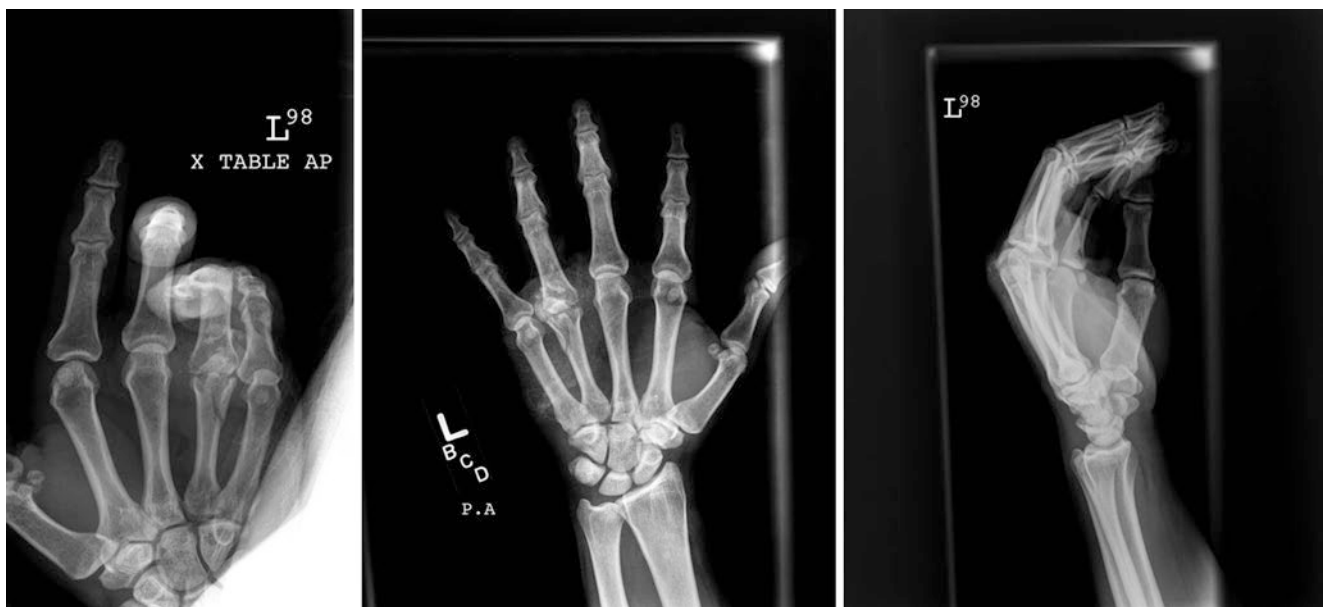


**Fig. 27.82** Staged external fixation antibiotic spacer in preparation for MCP arthrodesis

**Fig. 27.83** Radiographs following arthrodesis



Arthroplasty can also be considered when the fracture is felt to be unreconstructable but there is adequate bone stock for implants [27] (Figs. 27.84, 27.85, and 27.86).



**Fig. 27.84** Injury radiographs following GSW to ring MCP

**Fig. 27.85** Osteonecrosis of metacarpal head following ORI



**Fig. 27.86** Replacement arthroplasty



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## 28.1 Treatment Options and Goals

Many phalangeal fractures may be successfully treated with a variety of tapes, splints, or orthotics, including plaster splints, single-digit immobilization with aluminum or plastic splints, and occasionally casts.

The acknowledgment that multisystem trauma may force decision-making more toward operative intervention holds no more true than for phalangeal fractures, however. In the multisystem trauma scenario, the hand and arm may be critical for access in monitoring, and splints may compromise these efforts. Also, the hands and the arms may become the patient's legs, used for transfers, propulsion, and in some cases, even weight-bearing. Thus a phalangeal fracture that may be very nicely treated in a splint in isolation may be surgically stabilized to take the hand out of the injury picture.

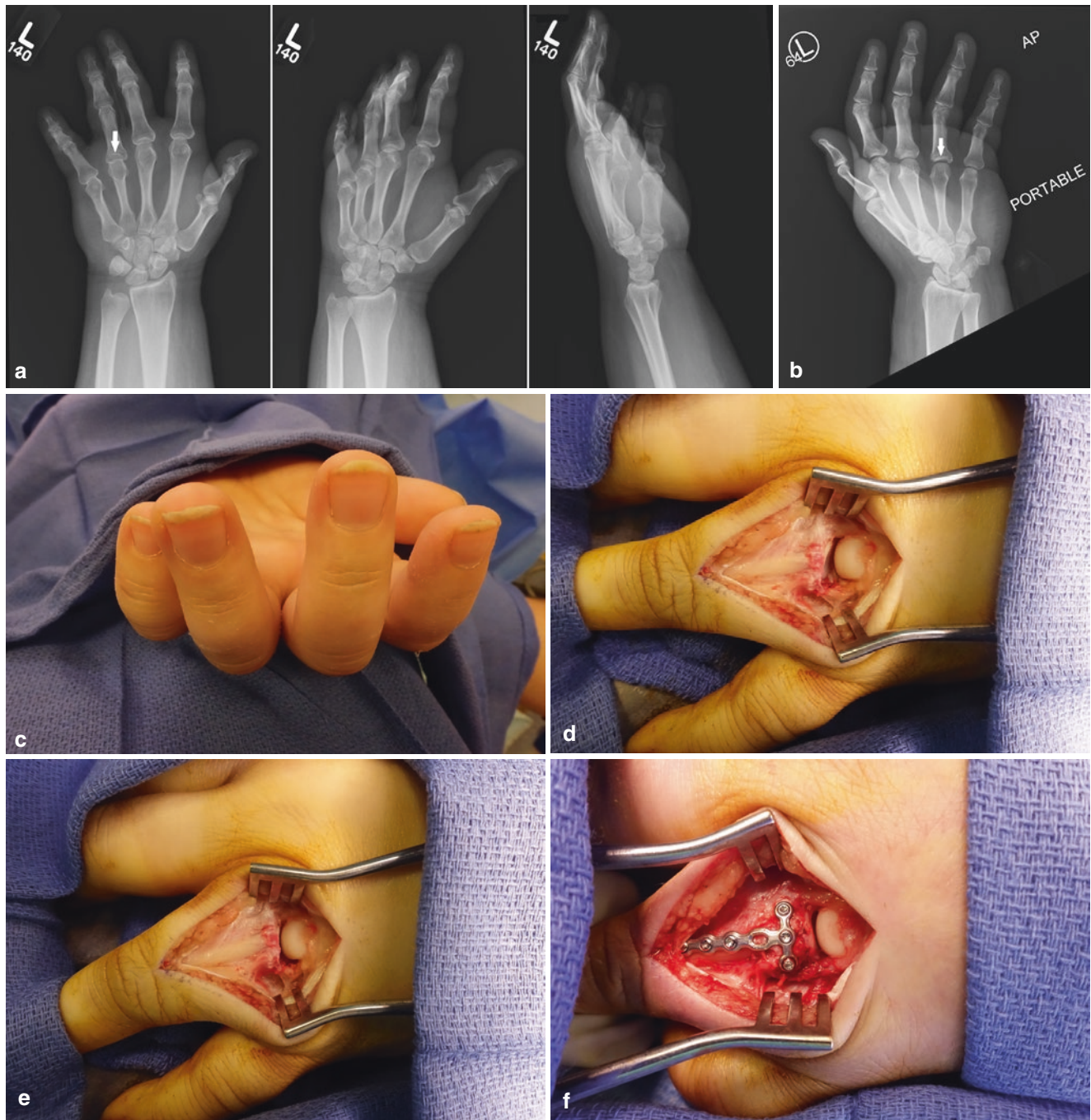
The treatment options for fixation are probably greater for the fingers and phalanges because less stress may be applied across the fixation during activities of daily living. Kirschner wires (K-wires), lag screws, interosseous wires (including cerclage fixation), external fixation, plates, and sutures all may be utilized. One fixation I tend not to use is percutaneous cross K-wires. I dislike this technique because I feel that you do not obtain good fixation, gliding structures (including tendon and skin) can be sheared, and the wires seem to cross at the fracture site and thus do not control rotation. The idea of a "quick pinning" has always intrigued me: I have seen thermally necrosed phalanges and resultant malunions created by multiple attempts at pin placement.

Regardless of the technique used, it is important to move the fingers and joint no later than 4 weeks from fixation because of a precipitous drop in ultimate range of motion outcomes. Early range of motion is important to minimize stiffness and prevent a negative outcome. Wright [1] and Strickland *et al.* [2] demonstrated the importance of initiating range of motion no later than 4 weeks. Hesitancy to move the patient early thus can negate the benefit from fixation.

Correlated with early range of motion is the need to correct digital overlap or scissoring, as malrotation can have an impact on the ability to adequately range the finger. Whatever the treatment option selected, correction of deformity is critical, because malrotation can have significant functional consequences (Fig. 28.1).

The proximal interphalangeal (PIP) joints are particularly important to keep supple, as they are the intercalated joint and can significantly affect hand function if stiff [3]. Hume *et al.* [4] have demonstrated a functional position and projected range of motion requirement for activities of daily living: approximately 60° at the metacarpophalangeal joint (MCP), 60° at the PIP, and 40° at the distal interphalangeal joint (DIP).

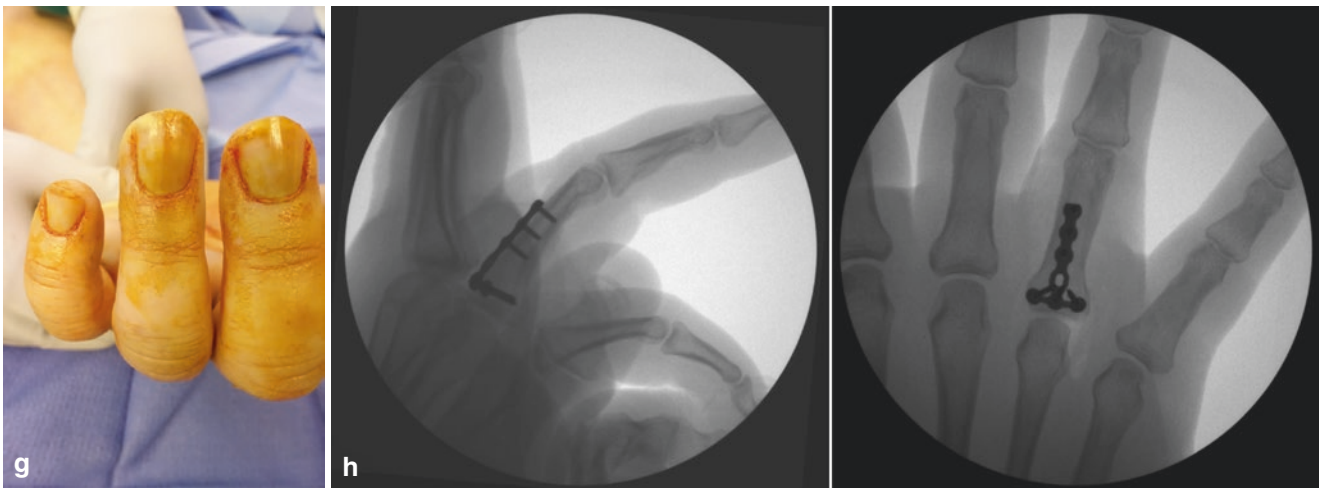
The treatment options I utilize are open reduction internal fixation (ORIF) with plates and rarely lag screws only, external fixation, longitudinal K-wires, or a combination of these techniques within a single phalanx. In multiple phalangeal fractures, a variety of these techniques may be used. The positioning, prepping, and draping are presented in Chap. 21.



**Fig. 28.1** (a) Radiographs of patient's left hand upon transfer from outside hospital with complaints of scissoring of ring finger. The official interpretation was no fracture, but close inspection at the ring base (*arrow*) demonstrates possible base fracture. (b) Patient obtained a true anteroposterior (AP) radiograph reflecting the importance of utilizing AP—not posteroanterior (PA)—radiographs of fingers. An impacted proximal phalanx fracture is noted (*arrow*). (c) Resting position of left

hand demonstrating rotated ring finger. (d) Dorsal approach to the metacarpophalangeal (MCP) joint, exposing the impacted proximal phalanx base. The finger is held in axial alignment. (e) Resting position demonstrating angulation of finger. (f) Dorsal fixation following elevation of articular fragment and bone graft from reamings from right humeral intramedullary fixation. (g) Clinical correction of rotation. (h) Radiographs following open reduction and internal fixation (ORIF)





**Fig. 28.1** (continued)

## 28.2 Open Reduction Internal Fixation

When ORIF is selected, I approach the phalanges generally through a straight, midline dorsal approach (Figs. 28.2, 28.3, and 28.4). I have tried curvilinear, S-type incisions and found them to be unnecessary.

The extensor over the proximal phalanx is generally split, however, sometimes in the distal aspect of the finger; I will reflect or elevate the lateral band, including release of the transverse retinacular ligament over the PIP joint. Reflecting the lateral band will allow access to the distal portion of the proximal phalanx, or the neck.



**Fig. 28.2** Dorsal incision for approach to proximal phalanx



**Fig. 28.3** Longitudinal incision in extensor



**Fig. 28.4** Metacarpophalangeal joint exposed to allow plate positioning for base and intraarticular fracture of the proximal phalanx

The middle phalanx is usually approached and plated radially or ulnarly, and I generally do not split the extensor over the middle phalanx, particularly avoiding disruption of the triangular ligament, which stabilizes the

lateral bands. An anterior approach is utilized occasionally for the distal phalanx, but usually for proximal phalangeal joint fractures such as a dorsal dislocation (Fig. 28.5).



**Fig. 28.5** (a) Injury radiographs of left small distal phalanx avulsion (Leddy and Packer Type III). (b) Radiographs following ORIF, with reinforced backup with 2.0 Prolene pullout suture

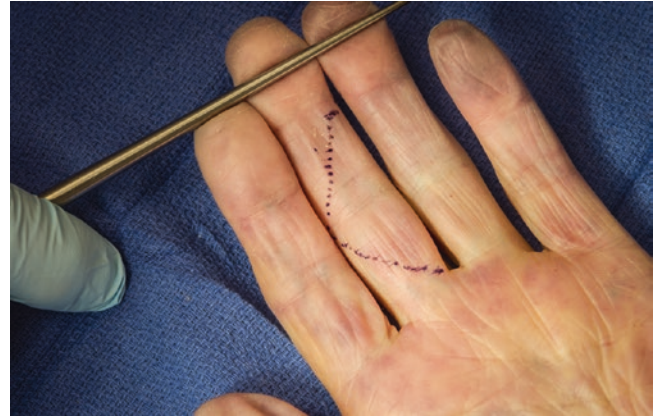


I use a Bruner incision with the broad base centered over the dominant digital artery. For the index and long fingers, the dominant digital arteries are ulnar, so the base is ulnarly oriented. In the ring and small fingers, the

dominant digital artery is radial, so the base is on the radial side (Figs. 28.6, 28.7, 28.8, 28.9, 28.10, 28.11, 28.12, 28.13, 28.14, 28.15, 28.16, 28.17, 28.18, 28.19, 28.20, and 28.21).



**Fig. 28.6** Bruner skin incisions outlined on left hand



**Fig. 28.7** Incision outlined for anterior approach to left long finger proximal interphalangeal (PIP) joint



**Fig. 28.8** Incision with gentle curve at apex of incision



**Fig. 28.9** Skin flap elevated over flexor sheath, with pickups at the distal end of the A2 pulley



**Fig. 28.10** Pickups at C1 pulley

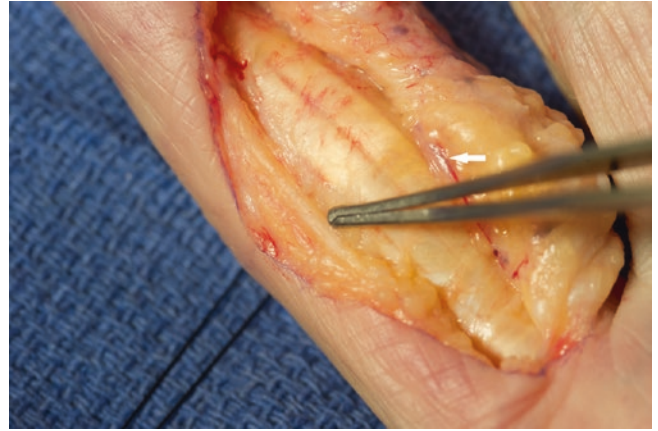


**Fig. 28.11** Pickups at A3 pulley





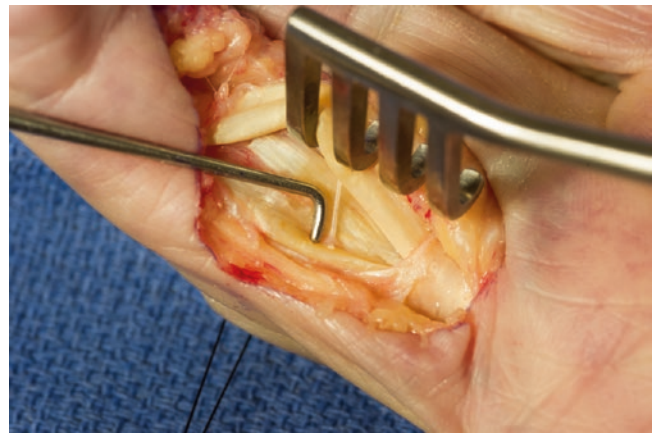
**Fig. 28.12** Pickups at C2 pulley



**Fig. 28.13** Radial digital nerve, pickups. The ulnar digital artery (arrow) and nerve are exposed



**Fig. 28.14** Incisions in sheath, developing distal ulnar and proximal radial flaps in sheath between the A2 and A4 pulleys



**Fig. 28.15** Sheath opened and flexor tendons exposed. The tendons are retracted, showing vincula longus

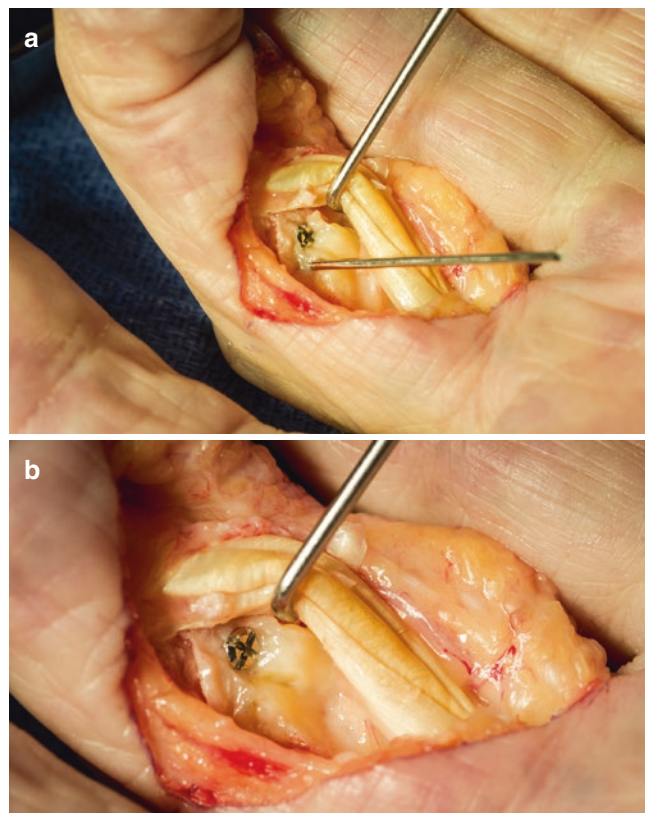


**Fig. 28.16** Flexor digitorum superficialis and flexor digitorum profundus retracted, exposing palmar plate



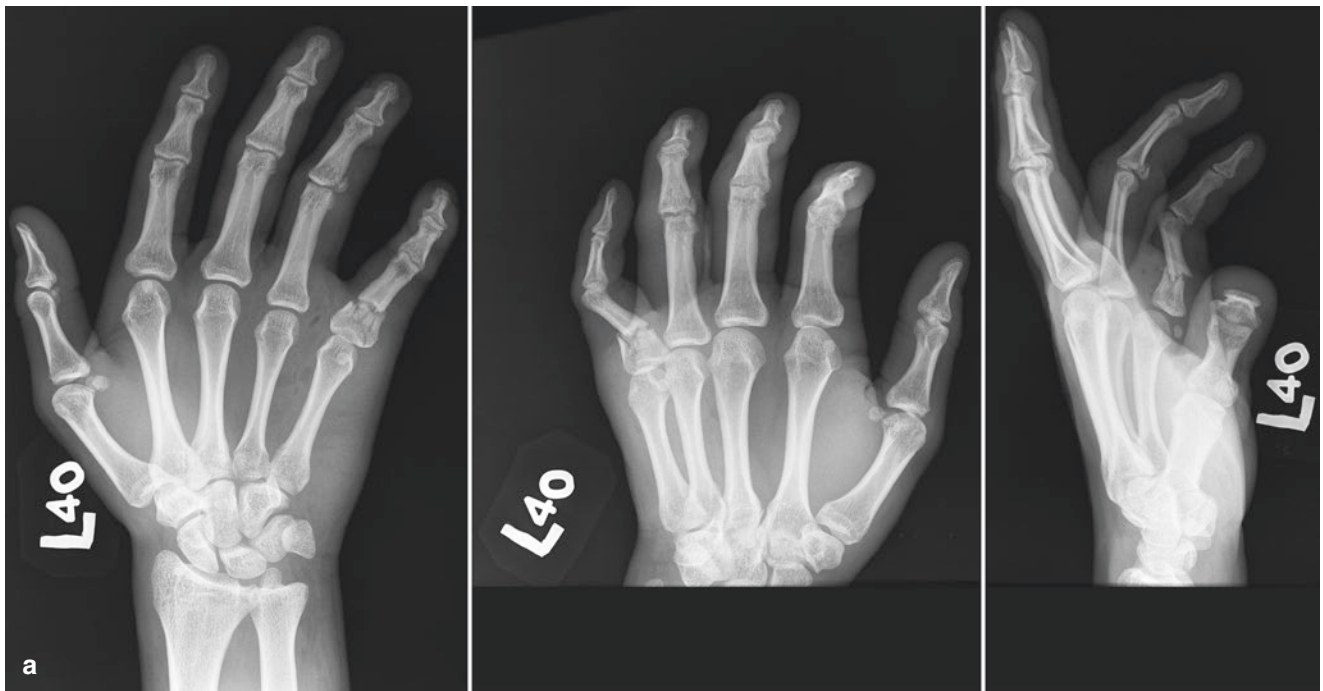
**Fig. 28.17** Palmar lip of middle phalanx osteotomized (fractured) (arrow)

**Fig. 28.18** (a) Fracture reduction and provisional Kirschner wire (K-wire) fixation followed by screw fixation. (Screw size for this demonstration is 1.5 mm, but clinically one would use one or two 1.0-mm or 1.3-mm screws.) (b) K-wire removal. Note palmar plate attachment preserved



**Fig. 28.19** (a) Injury radiographs of left ring finger PIP joint dorsal fracture dislocation. Note overlap of the fingers on lateral view despite efforts to attain spread finger. (b) Final radiographs following ORIF via an anterior approach



**Fig. 28.19** (continued)

**Fig. 28.20** (a) Injury radiographs of left ring finger middle phalanx avulsion fracture. (b) Postoperative radiographs following ORIF including two K-wires. (c) Radiographs following K-wire removal

**Fig. 28.20** (continued)





**Fig. 28.21** (a) Injury radiographs (AP and lateral views) of left ring finger PIP joint dorsal fracture dislocation. (b) Intraoperative radiograph following hemihamate arthroplasty shows an apparent step-off at

subchondral bone, but the articular joint is aligned. (c) Radiographs at discharge



The plate type, utilization of lag screws, and the number of screws used is very fracture-specific. I use lag screws rarely, only for oblique fractures (Fig. 28.22).



**Fig. 28.22** (a) Injury radiographs of right index proximal phalanx shaft fracture. (b) Radiographs following ORIF with lag screws

Recommendations for lag screw only use with two screws is that the fracture obliquity or length should be two times the diameter of the shaft at the fracture site [5], but these recommendations are rarely met in the fractures I encounter. Usually

there is a butterfly component to the long obliquity, obviating the lag screw-only technique. The plate selected is usually a 1.5-mm or 1.3-mm plate, and occasionally a 2.0-mm plate for a larger phalanx (Fig. 28.23, 28.24, 28.25, and 28.26).



**Fig. 28.23** (a) Injury radiographs of right ring finger proximal phalanx fracture. (b) Clinical photographs of rotated ring finger. (c) Incision incorporating laceration with split extensor tendon. (d) Reflected

periosteum exposing fracture. (e) Dorsal plate fixation. (f) Periosteum repaired with absorbable suture. (g) Extensor closure. (h) Radiographs following ORIF



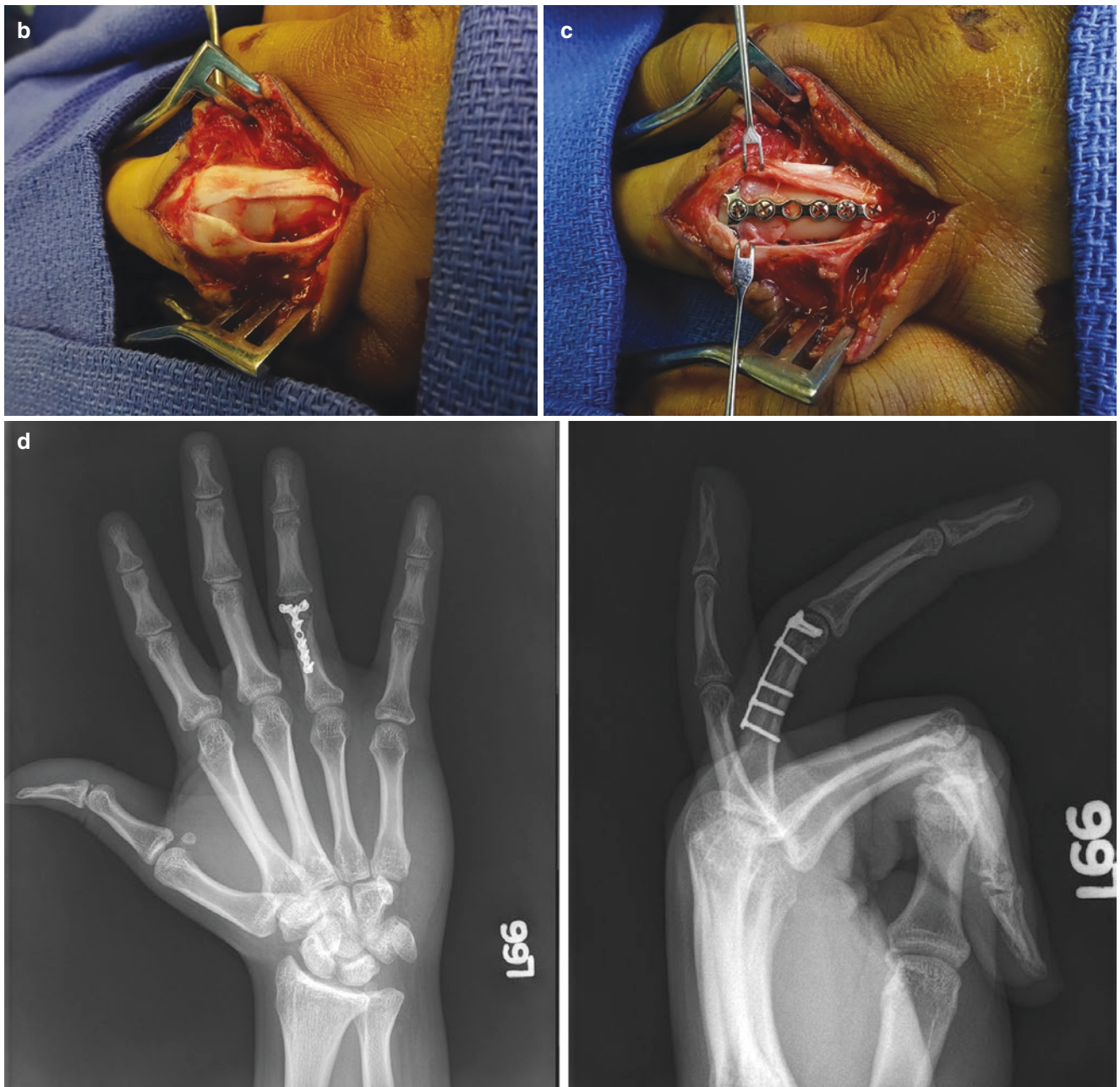


**Fig. 28.23** (continued)

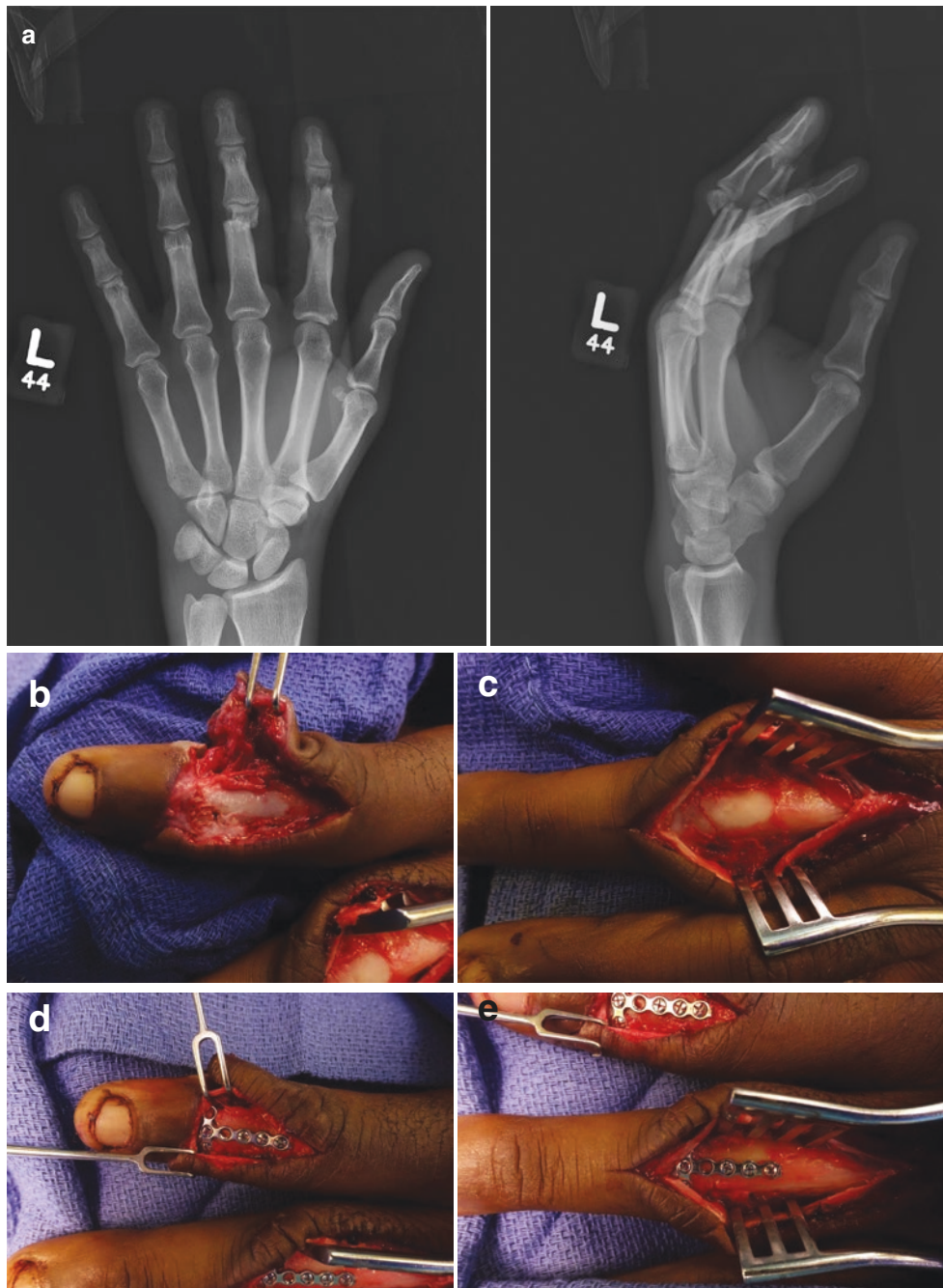




**Fig. 28.24** (a) Radiographs of left ring finger proximal phalanx fracture. (b) Dorsal approach to left ring finger proximal phalanx neck fracture. (c) Fixation following ORIF with dorsal nonlocking plate. (d) Radiographs following ORIF



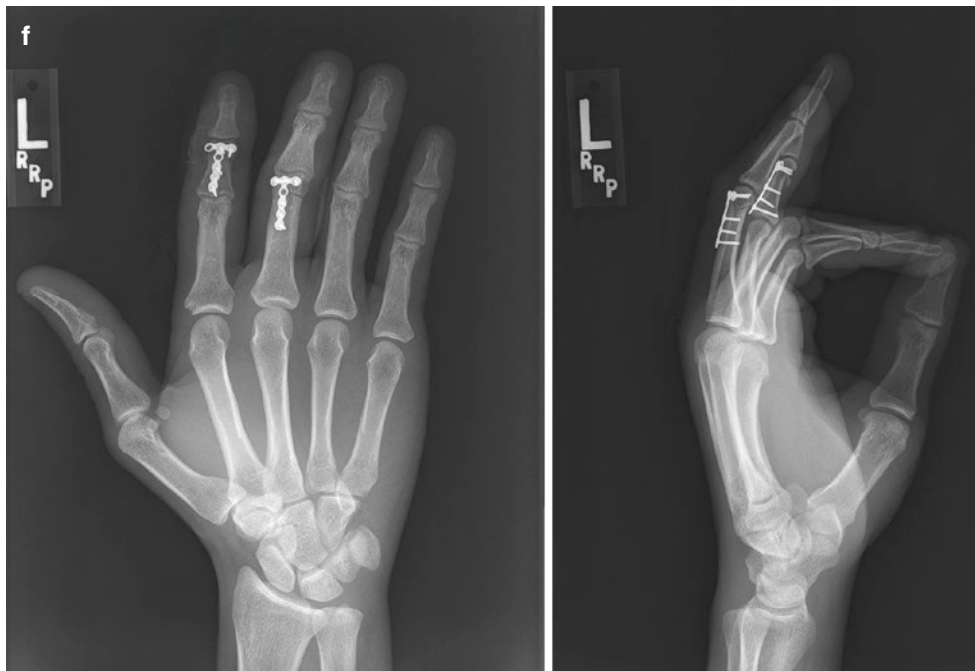
**Fig. 28.24** (continued)



**Fig. 28.25** (a) Injury radiographs of left index finger open middle phalanx and long finger proximal phalanx neck fracture. (b) Open left index middle phalanx fracture exposed. (c) Exposure of left long proximal

phalanx neck fracture. (d) Dorsal fixation of middle phalanx fracture with dorsal 1.5-mm T plate. (e) Dorsal fixation of proximal phalanx fracture with dorsal 1.5-mm T plate. (f) Radiographs following ORIF





**Fig. 28.25** (continued)



**Fig. 28.26** (a) Injury radiographs of left hand index finger middle phalanx fracture. (b) Radiographs following ORIF. (c) Radiographs at time of discharge. (Note AP projection.)



**Fig. 28.26** (continued)

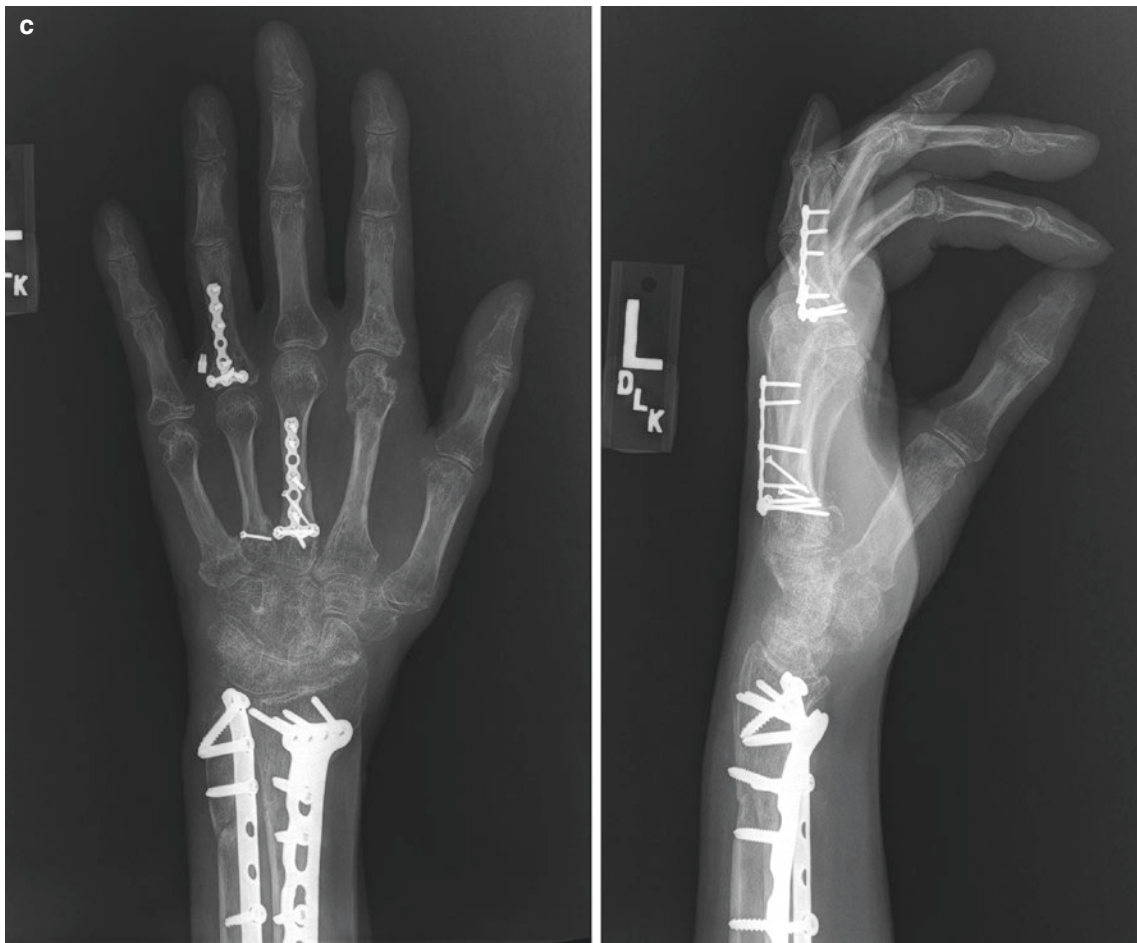
For diaphyseal fractures, four cortices on either side of the fracture is desirable, but I have used three or even two cortices on either side of the fracture. If you use a locking

system that has a preplaced guide system, be sure to account for all the guides before declaring “case done” (Fig. 28.27).



**Fig. 28.27** (a) Injury radiographs of multiple fractures to left hand. (b) Radiographs following fixation with multiple modalities. (c) Follow-up radiographs demonstrating retained guide (arrow)





A combination of techniques also can be used, including external fixation, temporary K-wire fixation, and internal fixation (Figs. 28.28 and 28.29).

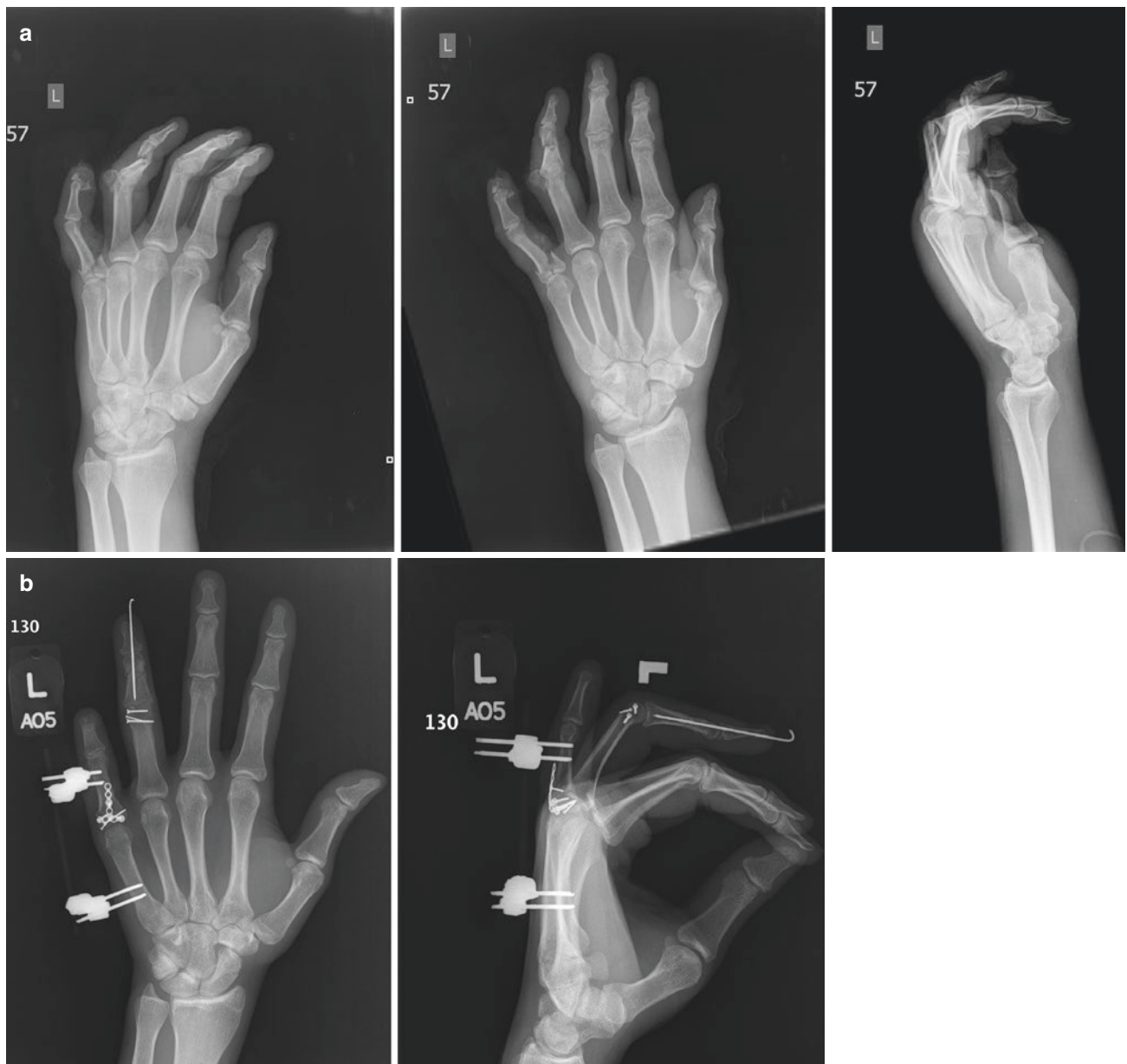


**Fig. 28.28** (a) Injury radiographs of multiple fractures of metacarpals and phalanges of left hand. (b) Radiographs following multiple stabilization techniques. (c) Radiographs prior to tenolysis, capsulectomies, and hardware removal. (d) Radiographs following multiple digital releases for contractures



**Fig. 28.28** (continued)





**Fig. 28.29** (a) Injury radiographs of left hand multiple injuries including small finger proximal phalanx base T-intercondylar fracture. (b) Radiographs following external fixation and ORIF of small finger fracture

### 28.3 External Fixation

External fixation of the fingers comes as a surprise to residents and fellows, who do not realize that this is a treatment option.

The usual indication is bone comminution or bone loss, as well as staging to subsequent ORIF, reminiscent of the treatment of lower extremity injuries. Sometimes bone loss obviates fixation and arthroplasty is performed (Fig. 28.30).



**Fig. 28.30** (a) Injury radiographs of right index finger PIP joint fracture. (b) Radiographs following provisional fixation. (c) Radiographs following replacement arthroplasty



**Fig. 28.30** (continued)



External fixation can be applied either unilaterally or in a transfixation system. I use the Stryker® external fixation system with 2-mm half pins or transfixation pins. I pre-drill with a 1.5-mm drill bit and use blunt half pins to avoid having a

sharp pre-drilling pin protruding through the opposite cortex and impinging on tendons. Proximal phalanx fractures can be stabilized with a spanning external fixator from the metacarpal to the phalanges distally (Fig. 28.31).



**Fig. 28.31** (a) Injury radiographs of right long finger proximal phalanx fracture. (b) External fixation spanning from metacarpal to proximal phalanx

The external fixator can be used as a spanning or unilateral fixator to a specific phalanx, as well as in combination with ORIF (Fig. 28.32).



**Fig. 28.32** (a) Injury radiographs of a comminuted open middle phalanx fracture of the left index finger. (b) Intraoperative traction reduction radiographs. (c) Radiographs following ORIF and external fixation. (d) Radiographs at discharge



Fig. 28.32 (continued)

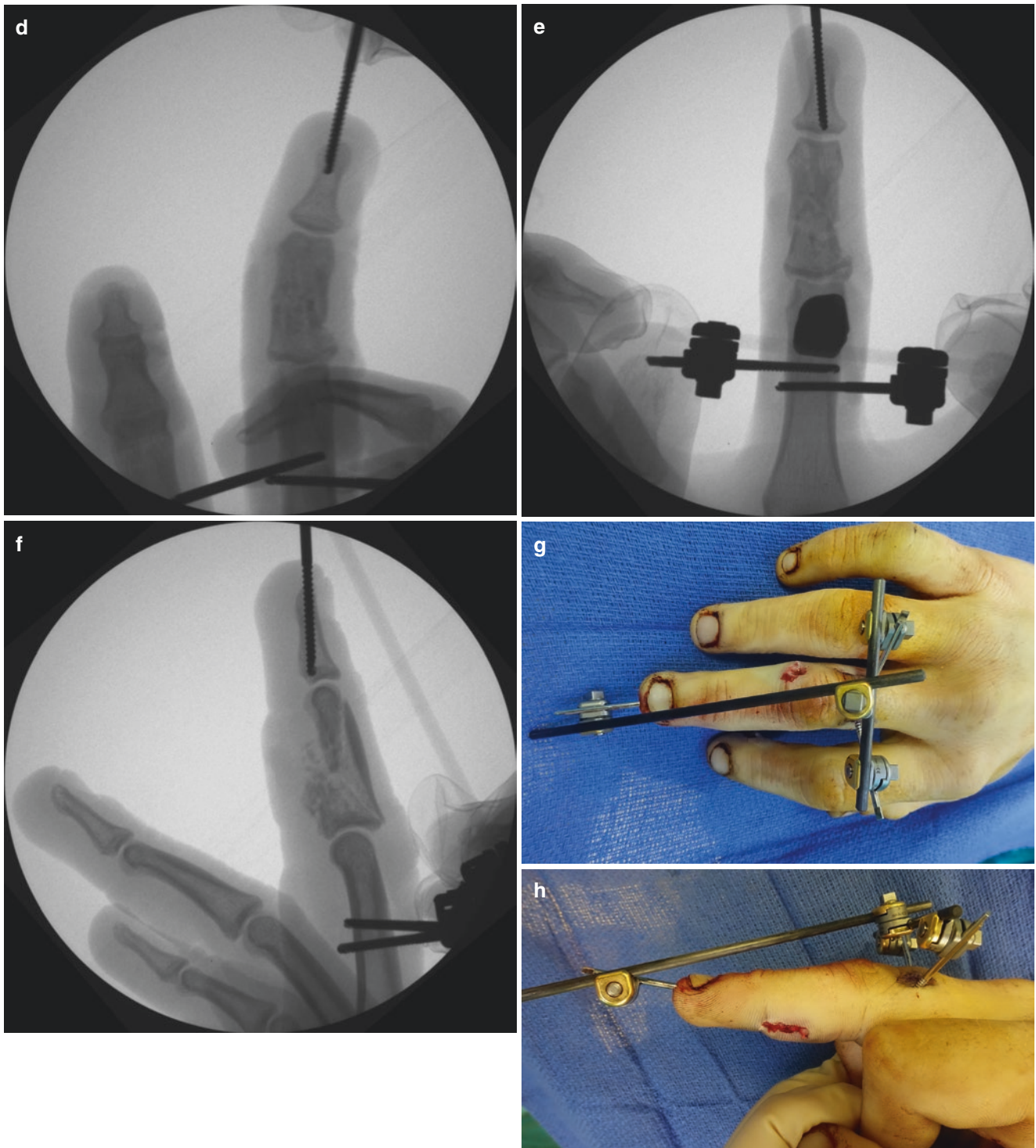


Comminuted middle phalanx fractures can be treated purely with distraction, with a longitudinal half pin in the distal phalanx (Fig. 28.33).

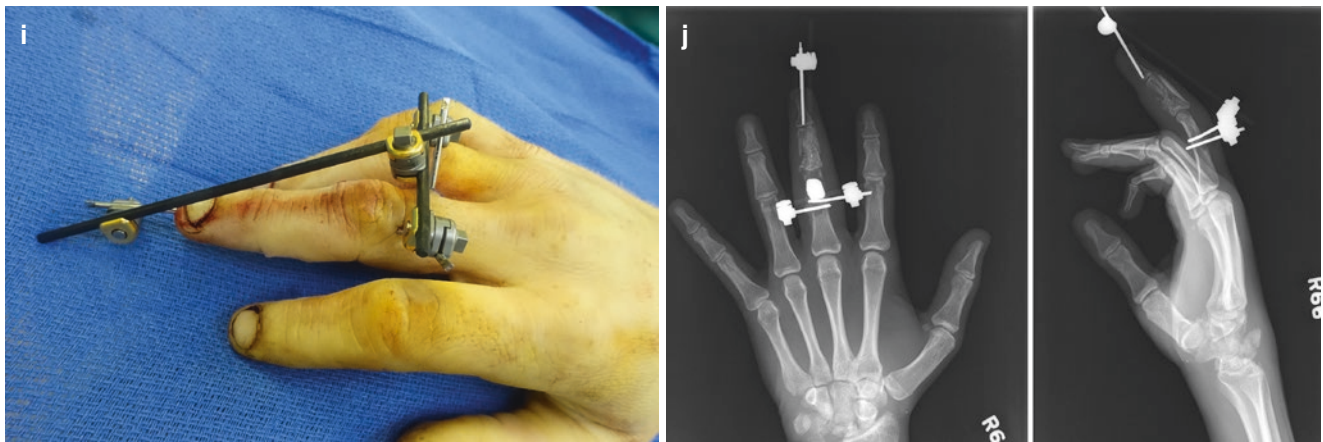


**Fig. 28.33** (a) Injury radiographs of right long finger middle phalanx fracture. (b–d) Intraoperative radiographs during external fixation insertion: Pre-drilling with 1.5-mm drill bit; insertion of 2-mm half pin.

(e–f) Final reduction. (g–i) Clinical photographs of external fixator on right long finger. (j) Radiographs prior to external fixator removal



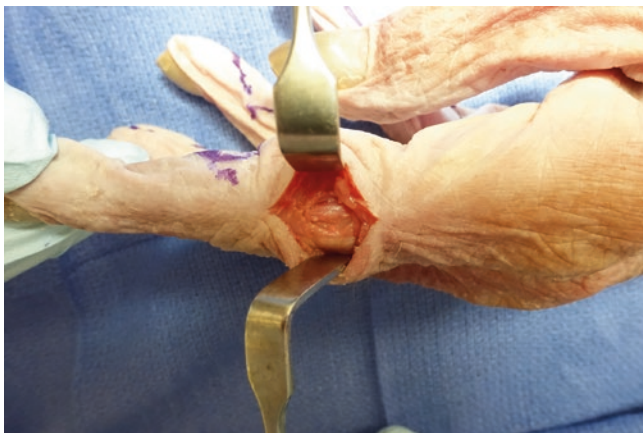
**Fig. 28.33** (continued)



**Fig. 28.33** (continued)

I try to apply the external fixator avoiding the lateral band extensor system (Fig. 28.34).

Regardless of the digit or phalanx treated, I try to remove the external fixator by 4 weeks, and no later than 6 weeks.



**Fig. 28.34** Incision along radial aspect of left index finger for external fixator pin insertion. Lateral band dorsal and exposed proximal phalanx



## 28.4 Longitudinal K-Wires

Despite my comment about crossing K-wires, I do occasionally use K-wires for fixation in fingers. I prefer longitudinally placed K-wires rather than oblique K-wires. Longitudinal K-wires may be placed across MCP joints for fractures of the base of the proximal phalanx, or retrograde

through the proximal phalanx head or through the fracture, followed by reduction and retrograde fixation (Figs. 28.35 and 28.36).

Retrograde fixation from the finger tip for phalangeal fractures can be tough, as the K-wire tends to slip off the distal phalanx tuft.



**Fig. 28.35** (a) Injury radiographs of left small finger proximal phalanx fracture. (b) Fixation and splint radiographs with fixation through metacarpal head. Note AP position of hand

**Fig. 28.36** (a) Injury radiographs of right long finger middle phalanx fracture with K-wire insertion through fracture. (b) Antegrade fixation, then reduction and retrograde fixation



## 28.5 Radiography and General Approach

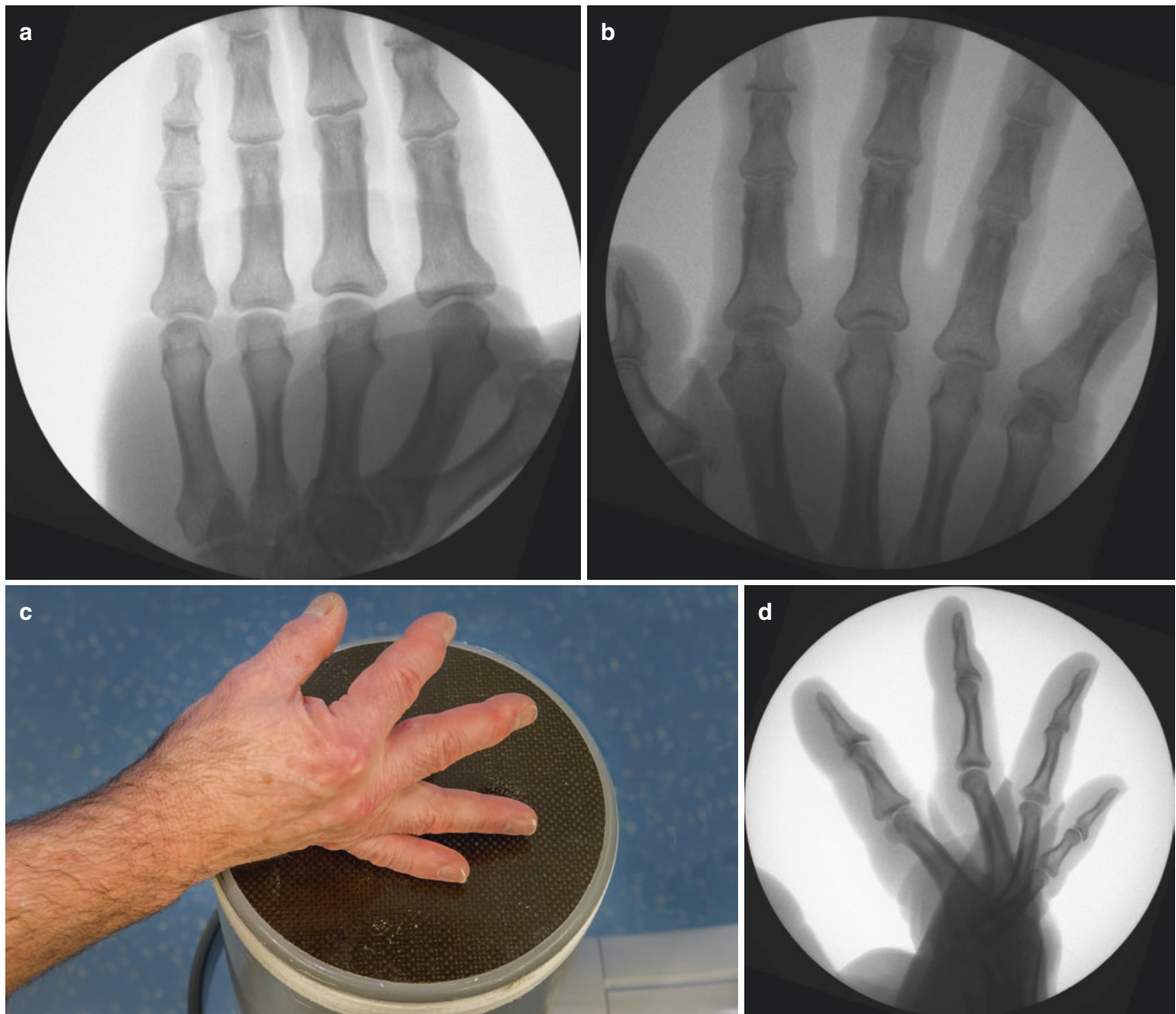
Whatever technique is employed, I prefer anteroposterior (AP) and spread lateral finger radiographs regardless of the finger undergoing fixation (Figs. 28.37 and 28.38). The AP projection, particularly from the metacarpal neck distally. Allows true orthogonal views. This is unlike the posteroanterior (PA) view, which automatically forces the hand into a rotated or oblique view because the thenar eminence bulk prevents the hand from lying flat.

Some of the examples shown in this chapter could be cited as controversial relative to fixation selection. I have not presented them as the definitive right answers, but I have often said to residents, “This may not be the right answer, but I don’t want to give the wrong answer.” That is, I cannot say that one technique is superior to another, but regardless of the technique used, it is important to try to avoid any potential negative ramifications consequent to the treatment options you choose.



**Fig. 28.37** AP radiographs of fingers for true perpendicular projection of the joint





**Fig. 28.38** (a) AP radiographs reflecting perpendicular projection and clearance of joints for better visualization. (b) PA radiographs of right hand demonstrating overlap of metacarpal and phalanges, obstructing

joint visualization. (c–d) Spread finger lateral to not overlap fingers, for individual finger visualization

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